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INTERNATIONAL CRITICAL TABLES  
OF  
NUMERICAL DATA  
PHYSICS, CHEMISTRY AND TECHNOLOGY  

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VOLUME II

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# INTERNATIONAL CRITICAL TABLES OF NUMERICAL DATA, PHYSICS, CHEMISTRY AND TECHNOLOGY

Prepared under the Auspices of the International  
Research Council and the National  
Academy of Sciences

BY THE  
NATIONAL RESEARCH COUNCIL  
OF THE  
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## VOLUME II

PUBLISHED FOR THE  
NATIONAL RESEARCH COUNCIL  
BY THE  
McGRAW-HILL BOOK COMPANY, INC.  
NEW YORK AND LONDON  
1927



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PRINTED IN THE UNITED STATES OF AMERICA

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## INTRODUCTION TO VOLUME II

This volume covers the characteristic properties of a variety of natural and industrial materials and products, together with some additional miscellaneous information of technological interest. Many of the materials treated in this volume are so variable in chemical composition or physical constitution, or both, that no critical evaluation of their properties in the ordinary sense of the term is possible. The values given have, therefore, been selected so as to portray one or all of the following: typical or average values with departures to be expected; maximum and (or) minimum values; range within which the value may be expected to fall; or (in cases where only fragmentary data are available) the values as recorded in the literature. In other cases, such as metals and alloys, commercial glasses, saccharimetry, etc., greater exactness is possible as the materials or substances dealt with have been or can be more or less exactly controlled as to chemical composition and physical condition. In the section on metals and alloys it has been deemed desirable to include most

of the industrially important properties of the pure metallic elements. Properties not so included in this section are treated in the succeeding volumes but for completeness are included in the index table on p. 358 of this volume.

Certain topics logically belonging in this volume have had to be omitted owing to failure on the part of the Cooperating Expert to submit his manuscript in time or owing to delays incident to revisions therein required by the Board of Editors. Such topics should be looked for in the appendix to Volume V.

To obviate frequent repetition the definitions of a number of mechanical properties used rather frequently in the volume are brought together on p. viii. Throughout the volume these definitions are cited in the form: "Def. 3," "Def. 16," etc.

In the first edition of a work of this magnitude and complexity errors will necessarily occur, and the Board of Editors will be grateful if the users of the International Critical Tables will call its attention to all errata noted.

## DEFINITIONS

**1. Proportional Limit.**—Stress at which the deformation ceases to be proportional to the load as determined by strainometer (extensometer for tension, compressometer for compression, and deflectometer for transverse tests, value being read from plotted results).

**2. Elastic Limit.**—In tensile and compressive tests: The stress at which the initial permanent elongation or shortening of the gage length occurs, as shown by an instrument of high precision (determined from set readings with extensometer or compressometer). In transverse tests: The extreme fiber stress at which the initial appreciable permanent deflection occurs as determined with deflectometer.

Tests are rarely made to determine the elastic limit, since such tests involve repeated application and release of load, and require considerable time. For practical purposes the elastic limit may be regarded as equal to the proportional limit.

**3. Yield Point.**—Stress at which marked increase in deformation of specimen occurs without increase in load as determined usually by drop of beam or with dividers for tensile, compressive, or transverse tests.

**4. Tensile, Compressive, or Shearing Strength (Ultimate).**—Maximum stress to which the test specimen is subjected by slowly increased load until rupture, divided by the original cross-sectional area of the test specimen.

**5. Modulus of Rupture.**—Maximum stress in the extreme fiber of a specimen tested to rupture, as computed by the empirical application of the flexural formula to stresses above the transverse proportional limit. For simple rectangular test piece with concentrated center load, it equals

$$\frac{1.5 \times \text{load} \times \text{span}}{\text{area} \times \text{depth}}$$

**6. Torsional Strength (or Modulus of Rupture in Torsion).**—Maximum stress in the extreme fiber of a specimen tested to rupture as computed by the empirical application of the torsional formula to stresses above the torsional proportional limit. For a round specimen it is

$$S = \frac{5.1 \times \text{twisting moment}}{\text{diameter}^3}$$

In ductile materials the stress at rupture may be considered uniformly distributed over the cross-sectional area and the above formula assumes the form

$$S = \frac{3.82 \times \text{twisting moment}}{\text{diameter}^3}$$

**7. Elongation.**—The percentage of elongation is found by dividing  $100 \times$  the increase of length after rupture by the original gage length. The percentage of elongation depends on the gage length. The elongation indicates the ductility of the material.

**8. Reduction of Area.**—The percentage of reduction is found as the ratio of  $100 \times$  the difference between the original and broken area of cross section to the original area. Reduction of area indicates generally the ductility of material.

**9. Poisson's Ratio.**—The ratio of lateral contraction per unit of diameter to longitudinal extension per unit of length of a bar under terminal tension within the elastic limit of material.

## DEFINITIONS

**1. Limite de proportionnalité.**—C'est la tension pour laquelle la déformation cesse d'être proportionnelle à la charge, cette tension étant déterminée à l'aide d'un appareil approprié: extensomètre pour la traction, compressomètre pour la compression, et déflectomètre pour les essais de flexion, la valeur de cette tension étant déduite d'une courbe tracée par points.

**2. Limite d'élasticité.**—Pour les essais de traction et de compression: c'est la plus petite tension pour laquelle la déformation permanente de la longueur entre repères devient appréciable au moyen d'un instrument de haute précision (cette tension étant déterminée au moyen des lectures effectuées à l'aide de l'extensomètre ou du compressomètre). Pour les essais de flexion: c'est la plus petite tension de la fibre extrême, pour laquelle la déformation permanente devient appréciable au moyen du déflectomètre.

Comme la détermination de la limite d'élasticité implique une succession de mises en charge et de décharges de l'éprouvette, et demande un temps considérable, ces essais sont rarement effectués. Dans la pratique on peut considérer la limite d'élasticité comme étant égale à la limite de proportionnalité.

**3. Limite d'étirage.**—C'est la tension pour laquelle se produit une augmentation importante de la déformation de l'éprouvette sans augmentation de la charge, cette détermination étant faite ordinairement par la chute de l'aiguille ou au compas pour les essais de traction, compression et flexion. (Limite élastique apparente.)

**4. Résistance à la traction, à la compression; Résistance au cisaillement.**—C'est l'effort maximum auquel l'éprouvette est soumise, par l'augmentation lente et progressive de la charge, jusqu'à rupture, divisé par la section transversale initiale de l'éprouvette.

**5. Module de rupture.**—C'est la tension maximum de la fibre extrême d'une éprouvette essayée jusqu'à rupture, ainsi qu'elle est calculée par l'application empirique de la formule de flexion, à une tension supérieure à la limite de proportionnalité de la flexion. Pour une éprouvette simple de section rectangulaire, avec une charge concentrée au milieu de la portée, elle est égale à:

$$1,5 \times \text{charge} \times \text{portée} / \text{section} \times \text{hauteur de la pièce}$$

**6. Résistance à la torsion (ou module de rupture à la torsion).**—C'est la tension maximum de la fibre extrême d'une éprouvette essayée jusqu'à rupture, ainsi qu'elle est calculée par l'application empirique de la formule de torsion à une tension supérieure à la limite de proportionnalité de la torsion. Pour une éprouvette de section circulaire, elle est égale à:

$$S = 5,1 \times \text{moment de torsion} / \text{diamètre}^3$$

Pour les matières ductiles, la tension lors de la rupture peut être considérée comme étant répartie uniformément dans la section transversale et la formule ci-dessus prend la forme:

$$S = 3,82 \times \text{moment de torsion} / \text{diamètre}^3$$

**7. Allongement.**—Le pourcentage d'allongement est obtenu en multipliant par 100 le rapport de l'augmentation de la longueur après rupture à la longueur initiale entre repères. Le pourcentage d'allongement dépend de la longueur entre repères. L'allongement donne une mesure de la ductilité de la matière.

**8. Striction.**—Le pourcentage de striction est le rapport multiplié par 100 de la différence entre la section initiale et la section de rupture à la section initiale. La striction donne généralement une mesure de la ductilité de la matière.

**9. Coefficient de Poisson.**—C'est le rapport de la contraction transversale (par unité de diamètre) à la dilatation longitudinale



## DEFINITIONEN

**1. Proportionalitäts-Grenze.**—Spannung, bei der die Formänderung aufhört proportional zur Belastung zu verlaufen; sie wird bestimmt durch ein Formänderungsmessinstrument (Dehnungsmesser für Zug, Zusammendrückungsmesser für Druck und Durchbiegungsmesser für Biegeversuche, der Punkt wird aus dem Diagramm ermittelt).

**2. Elastizitäts-Grenze.**—Bei Zug- und Druckversuchen: Diejenige Spannung bei der die erste bleibende Dehnung oder Verkürzung der Messlänge eintritt, bestimmt durch ein Messinstrument von hoher Präzision (bestimmt aus den Restablesungen am Dehnungs- oder Zusammendrückungsmesser). Bei Biegeversuchen: Die Spannung der äusseren Faser bei der die erste bemerkbar bleibende Durchbiegung eintritt, bestimmt mit dem Durchbiegungsmesser.

Versuche zur Bestimmung der Elastizitäts-Grenze werden selten ausgeführt, da solche Versuche wiederholte Belastung und Entlastung erforderlich machen und beträchtliche Zeit beanspruchen. Für praktische Zwecke kann die Elastizitäts-Grenze als gleichbedeutend mit der Proportionalitäts-Grenze angesehen werden.

**3. Streck-Grenze.**—Spannung, bei der ein deutliches Anwachsen der Formänderung der Probe eintritt, ohne dass die Belastung steigt, gewöhnlich bestimmt durch Absinken des Lastanzeigers oder an den Formänderungsmaßstäben für Zug-, Druck- oder Biegeversuch.

**4. Zug-, Druck- oder Scherfestigkeit (Höchstlast).**—Grösste Spannung, der die Probe unterworfen ist, bei langsamer Steigerung der Belastung bis zum Bruch, dividiert durch den ursprünglichen Probenquerschnitt.

**5. Biegespannung (oder Bruchmodul).**—Grösste Spannung in der äusseren Faser einer bis zum Bruch geprüften Probe in der Annahme, dass die empirische Biegeformel für Spannungen oberhalb der Proportionalitäts-Grenze angewendet werden kann. Für Proben mit einfachem rechteckigen Querschnitt und zentrischer Belastung gilt

$$1,5 \times \text{Last} \times \text{Stützweite} / \text{Querschnitt} \times \text{Höhe}$$

**6. Torsions-Festigkeit (oder Bruchmodul für Torsion).**—Grösste Spannung in der äusseren Faser der Probe beim Bruch, unter der Annahme, dass die Torsionsformel auch für Spannungen oberhalb der Proportionalitätsgrenze gilt. Für eine zylindrische Probe ist diese Torsions-Festigkeit

$$S = 5,1 \times \text{Drehmoment} / \text{Durchmesser}^3$$

Bei sehr formänderungsfähigen Materialien kann diese Bruchspannung als gleichmässig über den ganzen Querschnitt verteilt angesehen werden, und die obige Formel geht über in die Formel:

$$S = 3,82 \times \text{Drehmoment} / \text{Durchmesser}^3$$

**7. Bruchdehnung.**—Die prozentuale Dehnung wird gefunden, indem man die Längenzunahme nach dem Bruch durch die ursprüngliche Messlänge dividiert und mit 100 multipliziert. Die Bruchdehnung hängt von der Messlänge ab. Die Bruchdehnung ist ein Massstab für die Formänderungsfähigkeit des Materials.

**8. Querschnittsverminderung.**—Die prozentuale Querschnittsverminderung wird gefunden als das Verhältnis des Unterschiedes zwischen ursprünglichem und Bruchquerschnitt zu dem ursprünglichem Querschnitt multipliziert mit 100. Die Querschnittsverminderung zeigt allgemein die Formänderungsfähigkeit des Materials an.

**9. Poisson'sche Konstante.**—Das Verhältnis der Querkontraktion eines Stabes bezogen auf die Einheit des Durchmessers zur Längsdehnung, bezogen auf die Einheit der Länge eines

## DEFINIZIONI

**1. Limite di proporzionalità.**—È quel valore della forza applicata dopo il quale le deformazioni cessano di essere proporzionali alla forza stessa. Le deformazioni sono misurate da apposito apparato (estensometro per le prove di trazione, compressometro per le prove di compressione, e deflettometro o flessimetro per le prove alla flessione). I valori vengono desunti da grafici.

**2. Limite elastico.**—Nelle prove di trazione e compressione. È quel valore della forza al quale corrisponde l'inizio dell'allungamento o del riaccoreciamento permanente. La deformazione permanente è messa in evidenza da un istrumento di alta precisione, e determinata mediante una serie di letture all'estensometro o compressometro.

Nelle prove di flessione. Quel valore della forza che si ha nella fibra estrema quando si manifesta una deflessione permanente apprezzabile determinata con il flessimetro.

Le prove per determinare il limite di elasticità si eseguono raramente, perchè richiedono ripetute applicazioni ed annullamenti della forza applicata, e quindi molto tempo. Per scopi pratici, si può considerare il limite di elasticità come coincidente con il valore del limite di proporzionalità.

**3. Punto di snervamento.**—È quel valore della forza in corrispondenza del quale si ha un aumento marcato nella deformazione del provino senza che il carico aumenti. Esso viene determinato osservando il momento in cui l'apparato registratore della forza applicata al provino cade rapidamente, oppure a mezzo di misurazione sul provino calibrato alle prove di trazione, compressione e flessione.

**4. Carico di rottura alla trazione, compressione e taglio.**—È il valore massimo dello sforzo al quale il provino è soggetto alla rottura, quando lo sforzo viene accresciuto lentamente. Questo valore viene riferito all'area della sezione trasversale primitiva del provino.

**5. Modulo di rottura.**—Massimo sforzo che si verifica nelle fibre maggiormente sollecitate di un provino che venga provato a flessione fino a rottura. Esso è calcolato con l'applicazione empirica della formula di sollecitazione per flessione, anche quando lo sforzo supera il limite di proporzionalità per sollecitazione della flessione stessa. Per pezzi di forma rettangolare semplice con carico concentrato nel centro, è eguale a:

$$\frac{1,5 \times \text{carico} \times \text{distanza tra gli appoggi}}{\text{area} \times \text{spessore}}$$

**6. Sforzo di torsione (oppure modulo di rottura alla torsione).**—Massimo sforzo che si verifica nelle fibre più sollecitate di un provino provato fino alla rottura, calcolato applicando empiricamente (anche al di sopra del limite di proporzionalità per torsione) la formula che dà la sollecitazione per torsione. Per un provino a sezione rotonda, la formula è:

$$S = \frac{5,1 \times \text{momento torcente}}{\text{diametro}^3}$$

Nei materiali duttili lo sforzo di rottura può essere considerato uniformemente distribuito sull'area della sezione trasversale, e la formula (2) diventa:

$$S = \frac{3,82 \times \text{momento torcente}}{\text{diametro}^3}$$

**7. Allungamento.**—L'allungamento percentuale è calcolato dividendo l'aumento di lunghezza dopo rottura per la lunghezza originale calibrata. L'allungamento percentuale dipende dalla lunghezza calibrata, cioè dalla lunghezza alla quale è riferito l'allungamento stesso. Questo allungamento indica la duttilità dei materiali.



**10. Modulus of Elasticity ((a) in Tension or (b) in Compression).—**Ratio of stress within the proportional limit to the corresponding strain as determined with a precise extensometer. Accurate determinations of the modulus of elasticity are made with a gage length at least 8 in. (203.2 mm) in length.

**11. Modulus of Elasticity in Shear.—**Ratio of stress within the proportional limit to the corresponding angular strain (in radians). The following theoretical relation exists between the modulus of elasticity in shear and the modulus of elasticity:

$$G = \frac{E}{2(1 + \lambda)}$$

where  $G$  is the modulus of elasticity in shear,  $E$  modulus of elasticity, and  $\lambda$  Poisson's ratio.

It is difficult to make a direct experimental determination of  $G$  on account of the presence of other stresses. It is usually determined by the torsion of a round bar.

**12. Brinell Hardness Number.—**Ratio of load, on a sphere used to indent the material to be tested, to the area of the spherical indentation produced. The standard sphere used is a 10 mm diameter hardened steel ball. The loads are (a) 3000 kg (6615 lb.) and (b) 500 kg (1102 lb.), and the time of application of load is 30 sec. Values shown in the tables are based on spherical areas computed from measurements of the diameters of the spherical indentations, by the following formula:

$$H_B = \frac{P}{\pi h D} = \frac{P}{\pi D \left( \frac{D}{2} - \sqrt{\frac{D^2}{4} - \frac{d^2}{4}} \right)}$$

$P$  being load in kg,  $h$  being depth of indentation,  $D$  being diameter of ball and  $d$  being diameter of indentation, all lengths being expressed in millimeters. Brinell hardness values have a certain relation to tensile strength, and hardness determinations may be used to determine tensile strengths approximately by employing the proper conversion factor for the material under consideration.

**13. Shore Scleroscope Hardness.—**Height of rebound of a diamond-pointed hammer falling on the object from a fixed, stated height through a tube under the acceleration due to its own weight. On very soft materials a "magnifier" hammer is used in place of the commonly used "universal" hammer, and values may be converted to the corresponding "universal" value by multiplying the reading by  $\frac{4}{3}$ .

**14. Erichsen Value.—**The test is conducted by supporting the sheet on a circular ring and deforming it at the center of the ring by a spherical-pointed tool. The depth of impression (or cup), in millimeters, required to obtain fracture is the Erichsen value.

**15. Bend Test.—**(a) Angle through which the material can be bent without fracture; or (b) the number of bendings around a predetermined diameter; or (c) a minimum diameter around which the test piece can be bent through a stated angle.

**16. Impact Resistance.—**(Bibliography on Impact Testing, Whittemore, *Proc. A. S. T. M.*, 1922.) Indicates the shock-resisting qualities of material. Is of particular value in ascertaining the influence of heat treatment. Impact value depends on the form of the specimen and type of apparatus, both of which must be stated.

(par unité de longueur) d'une barre soumise à une tension inférieure à la limite d'élasticité de la matière.

**10. Module d'élasticité (a) de traction, (b) de compression.—**C'est le rapport de la tension (celle-ci étant inférieure à la limite de proportionnalité) à la dilatation correspondante, cette détermination étant faite au moyen d'un extensomètre de précision. Les déterminations précises du module d'élasticité se font sur une longueur entre repères d'au moins 203,2 mm.

**11. Module d'élasticité de glissement.—**C'est le rapport de la tension (celle-ci étant inférieure à la limite de proportionnalité) au glissement correspondant (en radians). Il existe entre le module d'élasticité de glissement et le module d'élasticité la relation théorique suivante:

$$G = \frac{E}{2(1 + \lambda)}$$

ou  $G$  est le module d'élasticité de glissement,  $E$  le module d'élasticité et  $\lambda$  le coefficient de Poisson.

Il est difficile de faire une détermination expérimentale directe de  $G$  par le fait de la présence d'autres tensions.  $G$  est ordinairement déterminé par la torsion d'une barre de section circulaire.

**12. Nombre de dureté Brinell.—**C'est le rapport de la charge appliquée sur une bille qui pénètre dans la matière à essayer, à la surface de l'empreinte sphérique produite. La bille type utilisée est une sphère en acier trempé de 10 mm de diamètre. Les charges sont de (a) 3000 kg et (b) 500 kg et la durée d'application de la charge est de 30 secondes. Les valeurs données dans les tables sont basées sur les surfaces des calottes sphériques calculées d'après les diamètres mesurés des empreintes sphériques produites, par la formule suivante:

$$H_B = \frac{P}{\pi h D} = \frac{P}{\pi D \left( \frac{D}{2} - \sqrt{\frac{D^2}{4} - \frac{d^2}{4}} \right)}$$

$P$  est la charge en kg,  $h$  la profondeur de l'empreinte,  $D$  le diamètre de la bille et  $d$  le diamètre de l'empreinte, toutes les longueurs étant exprimées en millimètres.

Il y a une certaine relation entre les nombres de dureté Brinell et la résistance de rupture, et des déterminations de dureté peuvent être employées pour déterminer approximativement la résistance de rupture en employant le facteur de conversion relatif à la matière considérée.

**13. Dureté au scléroscope de Shore.—**C'est la hauteur de rebondissement d'un petit marteau à pointe de diamant tombant sous l'effet de son propre poids sur l'objet d'une hauteur fixe définie, en se déplaçant dans un tube. Lorsqu'il s'agit de matières très tendres, on utilise un marteau amplificateur à la place du marteau "universel" généralement employé, et les valeurs peuvent être converties en valeurs "universelles" correspondantes en multipliant la lecture par  $\frac{4}{3}$ .

**14. Nombre d'Erichsen.—**On effectue l'essai en supportant la tôle sur une bague circulaire et en la déformant au centre de la bague par un outil à pointe sphérique. Le nombre d'Erichsen est la profondeur de l'empreinte exprimée en millimètres, nécessaire pour produire la rupture.

**15. Essai de pliage.—**(a) C'est l'angle sous lequel la matière peut être pliée sans rupture; ou (b) le nombre de pliages successifs autour d'une barre de diamètre prédéterminé; ou (c) le diamètre minimum du cylindre autour duquel l'éprouvette peut être pliée sous un angle défini.

**16. Résistance au choc.—**(Bibliographie concernant l'essai de choc, Whittemore, *Proc. A. S. T. M.*, 1922.) Elle donne une mesure des qualités de résistance de la matière au choc. Elle est d'une importance particulière pour se rendre compte de l'influence d'un traitement thermique. Les valeurs obtenues aux essais de choc dépendent de la forme de l'éprouvette et du type d'appareil employé; ces deux éléments doivent être définis.



Stabes bei bestimmten Zugspannungen innerhalb der Elastizitätsgrenze des betreffenden Materials.

**10. Elastizitäts-Modul (a) für Zug oder (b) für Druck.**—Das Verhältnis der Spannung innerhalb der Proportionalitätsgrenze zur entsprechenden Formänderung, ermittelt durch einen präzisen Dehnmessmer. Genaue Bestimmungen Elastizitätsmoduls werden ausgeführt mit einer Mindestmesslänge von 203,2 mm.

**11. Elastizitäts-Modul bei Scherbeanspruchung.**—Verhältnis der Spannung innerhalb der Proportionalitätsgrenze zu der entsprechenden Winkeländerung (in radians). Die folgende theoretische Beziehung besteht zwischen dem Elastizitätsmodul bei Scherbeanspruchung und den Elastizitätsmodul bei Zugbeanspruchung  $G = E/2(1 + \lambda)$ , worin  $G$  der Elastizitätsmodul für Scherbeanspruchung,  $E$  der Elastizitätsmodul für Zugbeanspruchung und  $\lambda$  die Poisson'sche Konstante ist. Es ist schwer, den Gleitmodul  $G$  direkt experimentell zu bestimmen wegen des Vorhandenseins von Nebenspannungen. Gewöhnlich wird er bestimmt durch einen Drehversuch mit einem Rundstab.

**12. Brinell Härtezahl.**—Das Verhältnis der Last, mit der eine Kugel in das zu prüfende Material eingedrückt wird, zur Fläche des erzeugten Kugeleindrucks. Die gebräuchliche Normalkugel ist eine gehärtete Stahlkugel von 10 mm Durchmesser. Die Kugelbelastungen sind (a) 3000 kg (6615 engl. Pfund) und (b) 500 kg (1102 engl. Pfund). Die Zeitdauer der Belastung beträgt 30 Sekunden. Die in den Tabellen angegebenen Werte für die Härtezahl werden aus Messungen der Durchmesser der erzeugten Kugeleindrücke unter Verwendung folgender Formel gewonnen:

$$H_B = \frac{P}{\pi h D} = \frac{P}{\pi D \left( \frac{D}{2} - \sqrt{\frac{D^2}{4} - \frac{d^2}{4}} \right)}$$

Darin bedeuten  $P$  die Kugelbelastung in kg,  $h$  die Eindringtiefe in mm,  $D$  den Kugeldurchmesser in mm und  $d$  den Durchmesser des Eindrucks in mm. Die Brinell-Härtezahlen haben eine gewisse Beziehung zur Zugfestigkeit, Härtebestimmungen können deshalb angewandt werden, um angenähert die Zerreißfestigkeiten zu bestimmen, unter Anwendung eigenen Koeffizienten eines für jedes Material.

**13. Shore Skleroskope-Härte.**—Die Höhe des Rückpralls eines mit Diamantspitze versehenen Fallhammers, der aus einer bestimmten festgelegten Höhe durch eine Röhre unter Beschleunigung durch sein Eigengewicht auf die Probe fällt. Bei sehr weichen Materialien wird ein Spezialhammer angewandt an Stelle des gewöhnlich benutzten "Universalhammers;" die mit diesem Spezialhammer erzielten Werte können auf den Universalhammer bezogen werden durch Multiplikation der Ablesungen mit  $\frac{4}{3}$ .

**14. Erichsen-Wert.**—Der Versuch wird ausgeführt, indem ein Blech am Rande kreisförmig eingespannt und in der Mitte durch einen kugelförmigen Stempel eingedrückt wird. Die Tiefe des Eindrucks (oder der Beule) in mm, die erforderlich ist um Bruch hervorzurufen, ist der Erichsen-Wert.

**15. Biegeprobe.**—(a) Winkel, um den das Material gebogen werden kann ohne zu brechen; oder (b) die Zahl der Biegungen um einen bestimmten Durchmesser; oder (c) der kleinste Durchmesser, um den die Probe um einen bestimmten Winkel gebogen werden kann.

**16. Schlag- oder Stossfestigkeit.**—(Bibliography on Impact Testing, Whittemore, *Proc. A. S. T. M.*, 1922.) Gibt die Eigenschaften eines Materials an, Stossbeanspruchungen zu widerstehen und ist von besonderem Wert zur Feststellung des Einflusses von Wärmebehandlung. Der gefundene Schlagfestigkeitswert hängt von der Form der Probe und der Art des Apparates ab, beides muss also festgelegt werden.

**17. Widerstand gegen Ermüdung.**—Widerstand eines Materials gegen wiederholte, zwischen zwei bestimmten Spannungsgrenzen

**8. Riduzione di area.**—Percentuale di riduzione di area calcolata come rapporto della differenza tra l'area del provino prima e dopo la rottura (nel punto dove è avvenuta la rottura) e l'area originale. La riduzione di area indica generalmente la duttilità dei materiali.

**9. Rapporto di Poisson.**—Il rapporto della contrazione laterale per unità di diametro e l'allungamento longitudinale, riferito alla unità di allungamento di una barra sottoposta, nei suoi estremi, a sollecitazioni di tensione entro i limiti di elasticità del materiale.

**10. Modulo di elasticità (a) alla trazione, (b) alla compressione.**—Il rapporto del valore dello sforzo entro i limiti di proporzionalità e le corrispondenti deformazioni determinate con un estensometro molto preciso. Determinazioni accurate del modulo di elasticità sono fatte sopra una lunghezza calibrata del provino di almeno mm 203,2.

**11. Modulo di elasticità al taglio.**—Rapporto del valore dello sforzo entro i limiti proporzionali corrispondenti alle deformazioni angolari espresse in radianti. La relazione teorica che esiste tra il modulo di elasticità al taglio e il modulo di elasticità è:

$$G = \frac{E}{2(1 + \lambda)}$$

dove  $G$  è il modulo di elasticità al taglio,  $E$  quello di allungamento e  $\lambda$  il rapporto di Poisson.

È molto difficile eseguire un esperimento per misurare direttamente il valore di  $G$ , a causa della presenza di altri sforzi. Generalmente viene determinato eseguendo una prova di torsione sopra una barra rotonda.

**12. Numero di durezza Brinell.**—Rapporto tra il carico applicato sopra una sfera che penetra nel materiale sottoposto alla prova e l'area della impronta prodotta.

La sfera tipo è del diametro di mm 10 ed è di acciaio temprato. I carichi applicati sono: (a) kg 3000; (b) kg 500. Il tempo di applicazione del carico è di 30 secondi.

I valori riportati nelle tabelle si riferiscono alla misura dell'area fatta in base al diametro dell'impronta sferica.

$$H_B = \frac{P}{\pi h D} = \frac{P}{\pi D \left( \frac{D}{2} - \sqrt{\frac{D^2}{4} - \frac{d^2}{4}} \right)}$$

dove  $P$  è il carico in kg,  $h$  la profondità dell'impronta,  $D$  il diametro della sfera adoperata e  $d$  il diametro della impronta. La durezza Brinell ha una certa relazione col carico di trazione, e le determinazioni della durezza possono servire a determinare appunto i carichi di trazione, in via approssimativa, mediante un fattore di conversione caratteristico per il materiale in esame.

**13. Durezza allo scleroscopio di Shore.**—Altezza del rimbalzo di un martello munito di una punta di diamante che cade sull'oggetto da una altezza nota e determinata, percorrendo un tubo sotto l'accelerazione dovuta al proprio peso. Per materiali molto teneri si usa un martello "moltiplicatore" invece del martello comune chiamato "universale," ed i valori possono essere convertiti in corrispondenti valori del martello universale moltiplicando la lettura per  $\frac{4}{3}$ .

**14. Valori di Erichsen.**—La prova si fa appoggiando il foglio di lamiera contro un anello e deformandolo nel centro a mezzo di un utensile pure sferico. La profondità dell'impressione in mm, che si ha per ottenere la frattura, è il valore di Erichsen.

**15. Prove di piegamento.**—(a) Angolo di cui il materiale può essere piegato senza fratturarsi, oppure: (b) numero di piegature attorno ad un predeterminato diametro, oppure: (c) diametro minimo attorno al quale il provino può essere piegato percorrendo un determinato angolo.

**16. Resistenza all'urto.**—(Bibliography on Impact Testing, Whittemore, *Proc. A. S. T. M.*, 1922.) Indica la resistenza del materiale all'urto, ed ha particolare valore per accertare l'influenza dei trattamenti termici. Il valore all'urto dipende dalla forma del provino e dal tipo della macchina, ed entrambi questi elementi devono essere specificati.



**17. Fatigue Resistance.**—Resistance of material to a load varying continuously and cyclically between two fixed stress values.

Numerical values of Fatigue Resistance for the case of zero mean stress (Reversed Stresses) may be given as follows:

**17a. Fatigue Strength.**—The numerical values of upper and lower limits of stress cycle which cause failure after a definite number of repetitions.

**17b. Endurance Limit.**—The value of the upper (or lower) limit of stress cycle which is just insufficient to cause failure after a stated number of repetitions have been endured.

**17c. True Endurance Limit.**—The limiting value of the endurance limit, *i.e.*, the upper limit of a cycle of stress which can be applied an indefinitely great number of times without causing failure. The true endurance limit can never, of course, be determined experimentally. For many materials, however, it is found that if values of fatigue strength are plotted against the number of cycles  $N$  to fracture (logarithmically or semi-logarithmically) the resulting curve tends to become parallel to the  $N$  axis, affording strong evidence of the existence of a "true endurance limit."

Numerical values of fatigue resistance for cycles of stress whose mean stress is *not* zero may be given by stating the upper and lower limits of the stress cycles corresponding to 17a above, or by stating the value of the mean stress and the range (or semi-range) of the cycle. Consequently, corresponding to the above we shall have:

**17d. Fatigue Strength Range.**

**17e. Endurance Range.**

**17f. True Endurance Range.**

**18. Ductility.**—The *ductility* is the elongation of the test specimen measured after rupture on a distance distributed symmetrically on both sides of the place of rupture, and should be specified in % of the original length of the distance.

**19. Acetyl Value.**—Defined as g KOH (56.1) to neutralize the acetic acid from 1000 g acetylated oil (1, 2, 7). It gives hydroxyacids + alcohols + oxidized fatty acids + unknown acids + mono- and di-glycerides + rancidity (7).

**20. Iodine Value.**—Per cent  $I_2$  or its equivalent of other halogen absorbed (3, 6, 12, 13). Heat of bromination is proportional to I-value for most non-oxidized oils and fats (4, 8).

**21. Saponification Value.**—Mg KOH for complete saponification of 1 g of the oil, fat or wax. The corresponding mean equivalent weight of the substance is the "saponification equivalent." (5) gives a method for cold saponification.

**22. Hehner Value.**—Per cent insoluble fatty acids + unsaponifiables.

**23. Polenske Value.**—Proportion of insoluble volatile fatty acids (in terms of  $cm^3$  of 0.1N KOH per 5 g of fat) obtained by Polenske's method of distillation (10).

**24. Acid Value.**—Mg KOH required to neutralize the free fatty acids in 1 g of oil or fat. The free fatty acids are also often expressed as a percentage of the principal fatty acid in the fat. Except in the case of the waxes, this value is not a constant, but varies with the degree of hydrolysis of the fat.

**25. Reichert-Meissl Value.**—Soluble volatile fatty acids in terms of 0.1N KOH per 5 g fat, under Meissl's test conditions (9, 11, 14).

## LITERATURE

(For a key to the periodicals see end of volume)

- (1) Benedikt and Ulzer, 57, 8: 41; 87. (2) Grün, *Oel-Fett Industrie*, 1: 339, 364; 19. (3) Hanus, 279, 4: 913; 01. (4) Hehner and Mitchell, 173, 20: 146; 95. (5) Henriques, 92, 8: 721; 95. 9: 221; 96. (6) Hübl, 112, 253: 281; 84. (7) Lewkowitch, 173, 24: 319; 99. (8) Marden, 45, 8: 121; 16. (9) Meissl, 112, 233: 229; 79. (10) Polenske, 279, 7: 273; 04. (11) Reichert, 91, 18: 68; 79. (12) Waller, 136, 10: 1831; 95. (13) Wijs, 25, 31: 750; 98. (14) Wollner, 173, 12: 203; 87. 352. 16: 609; 87.

**17. Résistance à la fatigue.**—Résistance des matériaux soumis à une sollicitation variant d'une façon continue et périodique entre deux valeurs fixes.

Les valeurs numériques de la résistance à la fatigue pour le cas d'un effort moyen nul (efforts alternatifs) peuvent être données comme suit:

**17a. Résistance à la fatigue.**—Ce sont les valeurs numériques des limites supérieures et inférieures du cycle de tension qui produisent la rupture après un nombre défini de répétitions de l'effort.

**17b. Limite d'endurance.**—C'est la valeur de la limite supérieure (ou inférieure) du cycle de tension qui est juste insuffisante pour produire la rupture après un nombre défini de répétitions de l'effort.

**17c. Limite d'endurance vraie.**—C'est la valeur limite de la limite d'endurance, c'est-à-dire la limite supérieure d'un cycle de tension, qui peut être appliqué un nombre indéfini de fois sans produire la rupture. La limite d'endurance vraie ne peut naturellement jamais être déterminée expérimentalement.

Cependant, pour plusieurs matériaux, on a constaté que si l'on représente graphiquement les valeurs de la résistance à la fatigue en fonction du nombre de cycles  $N$  jusqu'à rupture (logarithmiquement ou semi-logarithmiquement), la courbe qui en résulte tend à devenir parallèle à l'axe des  $N$ , mettant ainsi bien en évidence l'existence d'une "limite d'endurance vraie."

Les valeurs numériques de la résistance à la fatigue pour des cycles de tension dont la valeur moyenne *n'est pas* zéro, peuvent être obtenues en fixant la limite supérieure et la limite inférieure des cycles de tension correspondant à 17a ci-dessus, ou en fixant la valeur de la tension moyenne et l'amplitude (ou demi amplitude) du cycle. Par conséquent, correspondant à ce que nous avons ci-dessus, nous aurons:

**17d. Amplitude de la résistance à la fatigue.**

**17e. Amplitude d'endurance.**

**17f. Amplitude d'endurance vraie.**

**18. Ductilité.**—La *ductilité* est l'allongement d'une éprouvette essayée, mesuré après rupture sur une distance répartie symétriquement de part et d'autre de la section de rupture. Elle doit être exprimée en % de la longueur initiale entre repères.

**19. Indice d'acétyle.**—Il est défini par le nombre de g de KOH (56,1) nécessaires pour neutraliser l'acide acétique de 1000 g d'huile acétylée (1, 2, 7). Il donne les hydroxyacides + alcools + les acides gras oxydés + acides inconnus + mono et diglycérides + rancidité.

**20. Indice d'iode.**—Pourcentage de  $I_2$  ou son équivalent d'un autre halogène absorbé (3, 6, 12, 13). La chaleur de bromuration est proportionnelle à l'indice d'iode pour la plupart des huiles et graisses non oxydées (4, 8).

**21. Indice de saponification.**—Mg KOH pour la saponification complète de 1 g d'huile, graisse ou cire. Le poids équivalent moyen correspondant à la substance est "l'équivalent de saponification." (5) donne une méthode pour la saponification à froid.

**22. Indice de Hehner.**—Pourcent d'acides gras insolubles + insaponifiables.

**23. Indice de Polenske.**—Proportion d'acides gras volatils insolubles (exprimés en  $cm^3$  de 0,1N KOH pour 5 g de graisse) obtenue par la méthode de distillation de Polenske (10).

**24. Indice d'acide.**—Mg KOH nécessaires pour neutraliser les acides libres contenus dans 1 g d'huile ou de graisse. On exprime aussi souvent les acides gras libres en pourcent des acides gras principaux contenus dans la graisse. Excepté dans le cas des cires, cette valeur n'est pas une constante, mais elle varie avec le degré d'hydrolyse de la graisse.

**25. Indice de Reichert-Meissl.**—Acides gras volatils, solubles exprimés en 0.1N KOH pour 5 g de graisse, suivant les conditions de l'essai de Meissl (9, 11, 14).



schwingenden Beanspruchungen. Zahlenmässige Werte für den Ermüdungswiderstand können für den Fall, dass der Spannungsmittelwert Null ist (vollkommene Umkehrung der Spannung nach Richtung und Grösse) folgendermassen ausgedrückt werden:

**17a. Ermüdungsfestigkeit.**—Die zahlenmässigen Werte der oberen und unteren Grenzen des Spannungswechsels, welche nach einer bestimmten Anzahl von Wiederholungen Bruch hervorrufen.

**17b. Dauerbruchgrenze.**—Der Wert der oberen (od. unteren) Grenze des Spannungswechsels, welcher gerade noch nicht ausreicht, um den Bruch nach einer bestimmten Zahl von der Probe erlittener Lastwechsel hervorzurufen.

**17c. Wahre Dauerbruchgrenze.**—Der Grenzwert der Ermüdungsgrenze, d.h., die obere Grenze eines Spannungswechsels, welcher unbegrenzt häufig—ohne Bruch zu verursachen—angewandt werden kann. Die wahre Dauerbruchgrenze kann selbstverständlich niemals experimentell bestimmt werden. Sie ist jedoch für viele Materialien festgestellt, sobald man die Werte der Ermüdungsfestigkeit in Abhängigkeit von der Zahl der Spannungswechsel  $N$ , die zum Bruch führen, logarithmisch (oder für die eine Achse logarithmisch) aufgetragen, darstellt, die sich ergebende Kurve parallel zur  $N$ -Achse zu verlaufen strebt und damit einen sicheren Anhalt für das Vorhandensein einer "wahren Dauerbruchgrenze" bietet. Zahlenmässige Werte des Widerstandes gegen Ermüdung für Lastwechselfolgen, deren Spannungsmittelwerte nicht Null sind, können wiedergegeben werden durch Angabe der oberen und unteren Grenzen des Spannungswechsels, entsprechend 17a oder durch Angabe des Spannungsmittelwertes und der ganzen (oder halben) Amplitude. Entsprechend obigem, kann man demnach setzen:

**17d. Ermüdungsfestigkeit für bestimmte Spannungswechsel.**

**17e. Dauerbruchfestigkeit für bestimmte Spannungswechsel.**

**17f. Wahre Dauerbruchfestigkeit für bestimmte Spannungswechsel.**

**18. Formänderungsfähigkeit.**—Die Formänderungsfähigkeit ist die Verlängerung des Probestabes, gemessen nach dem Bruch auf eine Länge, die symmetrisch zu beiden Seiten der Bruchstelle verteilt ist. Sie ist in Prozenten der ursprünglichen Messlänge anzugeben.

**19. Acetyl-Zahl.**—Gibt die Gramme KOH (56,1) an, die für die Neutralisation der Essigsäure in 1000 g des acetylierten Öles notwendig sind (1, 2, 7). Damit sind bestimmt: Oxyssäuren + Alkohole + oxydierte Fettsäuren + unbekannte Säuren + Mono und Diglyceride + Ranzigkeit (7).

**20. Jod-Zahl.**—Ist durch Prozente Jod bestimmt (Äquivalent den anderen absorbierbaren Halogenen) (3, 6, 12, 13). Die Bromierungs-Wärme ist proportional der Jod-Zahl bei den meisten nicht oxydierten Fetten (4, 8).

**21. Verseifungs-Zahl.**—Gibt die mg KOH an die für die vollständige Verseifung von 1 g Fett, Öl, Wachs notwendig sind. Das entsprechende mittlere Äquivalent-Gewicht der Substanz ist das "Verseifungs-Äquivalent." (5) gibt eine Methode für die Verseifung in der Kälte.

**22. Hehner'sche-Zahl.**—Ist Prozente unlösliche Fettsäuren + Unverseifbares.

**23. Polenske-Zahl.**—Gibt die Anzahl  $\text{cm}^3$  0.1N KOH an die nötig sind, um die flüchtigen unlöslichen Fettsäuren für 5 g Fett zu neutralisieren, die entsprechend der Destillationsmethode nach Polenske (10) erhalten werden.

**24. Säure-Zahl.**—Ist die Anzahl mg KOH die für die Neutralisation der freien Fettsäuren von 1 g Öl oder Fett notwendig sind. Die freien Fettsäuren werden öfters in Prozenten der Hauptfettsäure im Fett angegeben. Mit Ausnahme bei den Wachsorten ist diese Zahl nicht konstant und ändert sich mit dem Grade der Hydrolyse des Fettes.

**25. Reichert-Meissl'sche-Zahl.**—Lösliche flüchtige Fettsäuren ausgedrückt in  $\text{cm}^3$  0.1N KOH für 5 g Fett, bestimmt nach dem Vorgange von Meissl (9, 11, 14).

**17. Resistenza alla fatica.**—Resistenza del materiale sottoposto a sforzi varianti in modo continuo e ciclico tra due valori fissi.

Valori numerici della resistenza alla fatica nel caso di uno sforzo medio eguale a zero (sforzi invertiti) possono essere indicati nella maniera seguente:

**17a. Resistenza alla fatica.**—I valori numerici dei limiti superiore ed inferiore delle sollecitazioni cicliche che producono rottura dopo un numero definito dei ripetizioni.

**17b. Limite di durata.**—Valore superiore (o inferiore) della massima sollecitazione ciclica insufficiente a produrre la rottura dopo essere stata applicata un determinato numero di volte.

**17c. Limite vero (o pratico) di durata.**—Valore limite del limite di durata, cioè valore superiore della massima sollecitazione ciclica che può essere applicata un gran numero di volte senza produrre rottura. Naturalmente, il vero limite di durata non può mai essere determinato sperimentalmente. Tuttavia, per molti materiali si è trovato che, se si riportano in un diagramma i valori della sollecitazione in funzione del numero di cicli  $N$  che producono la frattura (logaritmicamente o semilogaritmicamente) la curva risultante tende a divenire parallela all'asse  $N$  mostrando all'evidenza che esiste un "vero limite di durata."

Valori numerici di resistenza alla fatica per sollecitazioni cicliche nelle quali i valori medi delle sollecitazioni sono diversi a zero possono essere dati stabilendo i limiti superiore ed inferiore dei cicli delle sollecitazioni corrispondenti a 17a, oppure stabilendo il valore della sollecitazione media e l'intervallo (o semintervallo) del ciclo. Di conseguenza, d'accordo con quanto sopra si avrà:

**17d. Ampiezza delle oscillazioni tra i valori delle sollecitazioni cicliche alla fatica.**

**17e. Ampiezza od oscillazioni di durata.**

**17f. Ampiezza od oscillazioni pratiche di durata.**

**18. Duttilità.**—La duttilità è l'allungamento del provino, e viene misurata dopo la rottura sopra una lunghezza distribuita simmetricamente da entrambe le parti del punto di rottura. Essa è specificata in percento della lunghezza originale primitiva.

**19. Numero di acetile.**—Indica i grammi di KOH (56,1) necessari per neutralizzare l'acido acetico in 1000 g di olio acetilato (1, 2, 7). Esso è in relazione: con gli ossiacidi + gli alcoli + gli acidi grassi ossidati + acidi sconosciuti + mono e digliceridi, + la rancidità (7).

**20. Numero di iodio.**—Percento di  $\text{I}_2$  (o suo equivalente di altri alogeni) fissato (3, 6, 12, 13). Il calore di bromurazione è proporzionale al numero di iodio per la maggior parte degli oli e grassi non ossidati (4, 8).

**21. Numero di saponificazione.**—Mg di KOH necessari per la completa saponificazione di 1 g di olio, grasso o cera. Il corrispondente peso equivalente medio della sostanza è "l'equivalente di saponificazione." (5) dà un metodo di saponificazione a freddo.

**22. Numero di Hehner.**—Percento di acidi grassi isolubili + sostanze insaponificabili.

**23. Numero di Polenske.**—Quantità di acidi grassi volatili insolubili (riferito in  $\text{cm}^3$  di KOH 0.1N per 5 g di grasso) ottenuta col metodo di distillazione di Polenske (10).

**24. Numero di acidità.**—Mg di KOH richiesti per neutralizzare gli acidi grassi liberi di 1 g di olio o grasso. Gli acidi grassi liberi sono spesso riferiti come percentuale dell'acido principale contenuto nel grasso. All'infuori del caso delle cere questo numero non è una costante, ma varia col grado di idrolisi del grasso.

**25. Numero di Reichert-Meissl.**—Acidi grassi volatili solubili, espressi in  $\text{cm}^3$  di KOH 0.1N per 5 g di grasso, ottenuti nelle condizioni di procedimento Meissl (9, 11, 14).



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Index number.	Nombre index.	Index Nummer.	Numeri indice.	
Botanical name.	Nom botanique.	Botanischer Name.	Nome botanico.	
Family; genus and species.	Famille; genres et espèces.	Familie; Genus und Art.	Famiglia; genere e specie.	
Common name.	Nom commun.	Gebräuchlicher Name.	Nome comune.	
Place of growth of material tested.	Lieu où a poussé le matériel soumis aux essais.	Ort an dem das untersuchte Material gewachsen ist.	Luogo di origine del materiale esaminato.	
Seasoning condition.	Condition de séchage à l'air.	Trocknungsbedingungen.	Condizione di stagionatura.	
Bulk density of wood substance; oven-dry weight divided by volume in condition stated.	Densité apparente du bois; poids du bois séché au four divisé par le volume dans la condition spécifiée.	Raumgewicht des Holzes; Gewicht nach der Ofentrocknung dividiert durch das Volumen im angegebenen Zustand.	Densità della sostanza legnosa: peso dopo seccata al forno diviso per il volume nella condizione stabilita.	
Bulk density of piece; weight of sample divided by its volume in condition stated.	Densité apparente de la pièce; poids de l'éprouvette divisé par son volume dans la condition spécifiée.	Raumgewicht des Stückes; Gewicht der Probe dividiert durch das Volumen im angegebenen Zustand.	Densità del pezzo: peso del campione diviso per il suo volume nella condizione stabilita.	
Oven-dry.	Séché au four.	Ofen trocken.	Seccato al forno.	
Green.	Vert.	Frisch (grün).	Verde.	
Air-dry.	Séché à l'air.	Luft trocken.	Seccato all'aria.	
Moisture content.	Teneur en humidité.	Feuchtigkeitsgehalt.	Contenuto di umidità.	
Shrinkage from green to oven-dry condition.	Retrait à partir du bois vert lorsque séché au four.	Schwinden vom frischen bis zum Ofen trockenem Zustand.	Contrazione dallo stato verde a quello di essiccamento nel forno.	
Static and impact bending; compression parallel or perpendicular to grain.	Essai de flexion statique et au choc; compression parallèle et perpendiculaire à la fibre.	Statische und dynamische Biegefestigkeit; Druck parallel oder senkrecht zur Faser.	Incurvamento alla flessione statica e all'urto; compressione parallela o perpendicolare alla vena del legno.	
Fiber stress at elastic limit.	Tension de la fibre à la limite élastique.	Faserspannung an der Elastizitätsgrenze.	Trazione della fibra al limite di elasticità.	
Modulus of rupture.	Module de rupture.	Bruchfestigkeit.	Modulo di rottura.	
Modulus of elasticity.	Module d'élasticité.	Elastizitätsmodulus.	Modulo di elasticità.	
Work to elastic limit.	Travail jusqu'à la limite élastique.	Arbeit bis zur Elastizitätsgrenze.	Lavoro fino al limite di elasticità.	
Work to maximum load.	Travail jusqu'à charge maximum.	Arbeit bis zur Höchstlast.	Lavoro fino al carico massimo.	
Total work.	Travail total.	Gesamtarbeit.	Lavoro totale.	
Height of drop causing complete failure.	Hauteur de chute occasionnant une rupture complète.	Fallhöhe die zum vollkommenem Bruch führt.	Altezza del peso causante completa rottura.	
Maximum crushing strength.	Résistance maximum à l'écrasement.	Schlagfestigkeit.	Massima forza schiacciante.	
Shear; tension perpendicular to grain; hardness; cleavage.	Cisaillement tension perpendiculaire à la fibre; dureté; clivage.	Scherung; Druck senkrecht zur Faser; Härte; Spaltbarkeit.	Taglio; tensione perpendicolare alla vena; durezza; fendimento.	

## I. NORTH AMER-

## UNITED STATES FOREST

The following data on certain woods of North America are based on an extensive series of tests of small specimens free of defects. All the tests were conducted under a uniform procedure, so that the results are strictly comparable. Analysis of the test figures has made it possible to establish definite density-strength relations, which are represented by the equations given in the first section of the table (Table 1). These equations are all of the parabolic type, the degree being determined to the nearest quarter-unit. By substituting the appropriate specific gravity for a given species (columns 8 and 9) in the equation for any property, the value of the corresponding property may be obtained.

In most species, however, there is a very considerable departure of average test results from the general equation values, although very few species, thus far investigated, are either wholly above or wholly below normal, all properties considered. Since the deviation of a property from the normal value as determined by the equation often indicates the special fitness or unfitness of the species for a particular use, it becomes necessary to supplement the equations with departure factors, for the properties of each species. Such factors, expressed as *percentages* and listed in order below the respective equations, make up the second part of Table 1. By multiplying the value,  $F$ , computed by the equation, by the proper correction factor, the actual average value for the property and species in question may be determined.

*Example:* To find the modulus of rupture of air-dried shagbark hickory. The finding list shows this to be No. 62, *Hicoria ovata*. From the equation of column 15 we find  $F = 18.1 D_a^{1.25}$ . For No. 62 we find (column 9)  $D_a = 0.724$  and (column 15) correction factor = 119%, whence

$$F = 1.19 \times 18.1 \times (0.724)^{1.25} = 14.4 \text{ kg/mm}^2 = 14.4 \times 1422 = 20\,500 \text{ lb./in.}^2$$

The test methods that were used conform to Tentative Standard D143-24T of the American Society for Testing Materials, as set forth in *Proc. A. S. T. M.* 939; 24. (General description in U. S. Dept. Agr., *Bull.* No. 556.) The principal data relating to the procedure for each kind of test are summarized as follows:

**Shrinkage in Volume.**—Specimen  $5.08 \times 5.08 \times 15.24$  cm ( $2 \times 2 \times 6$  in.). Volume determined when green (unseasoned) and after oven-drying to constant weight at  $100^\circ\text{C}$ . Specimens thoroughly air-seasoned prior to drying in oven.

**Shrinkage, Radial and Tangential.**—Specimen  $2.54 \times 10.16 \times 2.54$  cm ( $1 \times 4 \times 1$  in.). Width measured when green (unseasoned) and after oven-drying to constant weight at  $100^\circ\text{C}$ . Specimens thoroughly air-seasoned prior to drying in oven.

**Static Bending.**—Specimen  $5.08 \times 5.08 \times 76.20$  cm ( $2 \times 2 \times 30$  in.). Center loading, 71.12 cm (28 in.) span. Load applied by testing machine head moving 0.254 cm (0.10 in.) per min. Total work is defined as that obtained by continuing the test until either a 15.24 cm (6 in.) deflection is reached or the load falls to 90.7 kg (200 lb.) or less.

**Impact Bending.**—Specimen and span as above. 22.7 kg (50 lb.) hammer dropped first from 2.54 cm (1 in.) height, next from 5.08 cm (2 in.) height, etc., up to 25.4 cm (10 in.), then from height increments of 5.08 cm (2 in.) until failure.

**Compression Parallel to Grain.**—Specimen  $5.08 \times 5.08 \times 20.32$  cm ( $2 \times 2 \times 8$  in.). End load, testing machine head moving 0.061 cm (0.024 in.) per min.

Les données indiquées ici, relatives à certains bois de l'Amérique du Nord, sont basées sur une série d'expériences faites sur de petites éprouvettes exemptes de défauts. Tous les essais ayant été effectués suivant une procédure uniforme, les résultats sont donc strictement comparables. L'analyse des chiffres obtenus aux essais a permis d'établir des relations définies entre la densité et la résistance, qui sont représentées par les équations inscrites dans la première section de la table (Table 1). Ces équations sont toutes du type parabolique, le degré étant déterminé au quart d'unité le plus proche. En substituant le poids spécifique approprié pour une espèce donnée (colonnes 8 et 9) dans l'équation relative à une propriété donnée, on peut obtenir la valeur correspondante de la propriété.

Cependant pour la plupart des espèces il y a un écart considérable entre les résultats moyens des essais et les valeurs déduites de l'équation générale; pour autant que les expériences effectuées l'ont démontré, il n'y a qu'un petit nombre d'espèces qui sont, ou en entier au-dessus ou en entier au-dessous de la normale pour toutes les propriétés considérées. Comme l'écart d'une propriété de la valeur normale, ainsi qu'elle est déterminée par l'équation, indique souvent la convenance spéciale de l'espèce pour un usage particulier, ou sa non-convenance, il est nécessaire de compléter les équations par des facteurs de correction pour les propriétés de chaque espèce. Ces facteurs, exprimés en pourcentage et inscrits dans l'ordre au-dessous des équations respectives, constituent la deuxième partie de la Table 1. En multipliant la valeur  $F$  calculée au moyen de l'équation par le facteur de correction convenable, on peut déterminer la valeur moyenne de la propriété de l'espèce en question.

*Exemple:* Soit à déterminer le module de rupture du "shagbark hickory" séché à l'air. La liste de recherches montre qu'il s'agit du No. 62 *Hicoria ovata*. De l'équation de la colonne 15 on trouve  $F = 18,1 D_a^{1.25}$ . On trouve pour le No. 62 (colonne 9)  $D_a = 0,724$  et (colonne 15) le facteur de correction = 119%, d'où

$$F = 1,19 \times 18,1 \times (0,724)^{1.25} = 14,4 \text{ kg/mm}^2 = 14,4 \times 1\,422 = 20\,500 \text{ lb./in.}^2$$

Les méthodes d'essais qui ont été utilisées sont conformes à l'examen type D143-24T de la société américaine pour l'essai des matériaux, ainsi qu'elles sont décrites dans *Proc. A. S. T. M.* 939; 24 (*cf.* U. S. Dept. Agr. *Bull.* 556). Les données principales relatives à la procédure pour chaque sorte d'essai sont rassemblées ci-dessous:

**Retrait en volume.**—Eprouvette  $5,08 \times 5,08 \times 15,24$  cm ( $2 \times 2 \times 6$  pouces). Le volume est déterminé lorsque le bois est vert, puis, après séchage à poids constant au four à  $100^\circ\text{C}$ . Avant le séchage au four, les éprouvettes sont complètement séchées à l'air.

**Retrait radial et tangentiel.**—Eprouvette  $2,54 \times 10,16 \times 2,54$  cm ( $1 \times 4 \times 1$  pouce). La largeur est mesurée sur le bois vert et après séchage à poids constant, au four à  $100^\circ\text{C}$ . Avant le séchage au four, les éprouvettes sont complètement séchées à l'air.

**Essai de flexion statique.**—Eprouvette  $5,08 \times 5,08 \times 76,20$  cm ( $2 \times 2 \times 30$  pouces); charge centrale; portée 71,12 cm (28 pouces). La charge est appliquée par une machine à essai dont la pièce mobile se déplace de 0,254 cm (0,10 pouces) à la minute. Le travail total est défini par celui qu'on obtient en continuant l'essai jusqu'à ce qu'une flèche de 15,25 cm soit obtenue, ou que la charge tombe à 90,7 kg (200 lb.) ou moins.



## ICAN WOODS

## PRODUCTS LABORATORY

Die hier angegebenen Werte bestimmter nordamerikanischer Hölzer ergeben sich aus einer ausgedehnten Serie von Prüfungen an einer kleinen Zahl von fehlerfreien Arten. Alle Prüfungen sind bei einheitlichem Vorgange ausgeführt worden, so, dass sie direkt vergleichbar sind. Die Analysen der Zahlenwerte der Prüfungsergebnisse machten es möglich gewisse Beziehungen zwischen Dichte und Festigkeit aufzustellen, die durch Gleichungen im ersten Abschnitt der Tafel 1 wiedergegeben sind. Diese Gleichungen sind alle vom parabolischen Typus, der Exponent in der Gleichung ist auf die nächste Viertel-Einheit bestimmt. Durch Einsetzung des entsprechenden spezifischen Gewichtes für eine bestimmte Art (Reihe 8 und 9) in die Gleichung für ihrgegend eine Eigenschaft, erhält man den Wert für die entsprechende Eigenschaft.

Bei vielen Arten jedoch ist eine bemerkenswerte Abweichung des durchschnittlichen Wertes des Prüfungsergebnisses von dem Werte, der sich aus der allgemeinen Gleichung ergibt, vorhanden. Es gibt indessen nur sehr wenige Arten, so weit untersucht, deren berücksichtigten Eigenschaften zur Gänze entweder über oder unter dem normalen Werten liegen. Da die Abweichung einer Eigenschaft, von dem durch die Gleichung erhaltenen Wert, häufig die besondere Eignung oder Nichteignung einer Art für eine besondere Verwendung anzeigt, wird es notwendig, für die Eigenschaft jeder einzelnen Art die Gleichung durch einen Abweichungsfaktor zu ergänzen. Solche Faktoren, in *Prozenten* ausgedrückt, befinden sich geordnet unter den entsprechenden Gleichungen und machen den zweiten Teil der Tafel 1 aus. Durch Multiplikation des Wertes  $F$ , der nach der Gleichung gefunden ist, mit dem eigenen Korrektionsfaktor, erhält man richtige Mittelwerte für die Eigenschaft des fraglichen Musters.

**Beispiel:** Es ist die Bruchfestigkeit von lufttrockenem Hykorynussbaum zu finden. Die Nachschlagsliste zeigt, dass dies No. 62 *Hicoria ovata* ist. Aus der Gleichung der Reihe 15 findet man  $F = 18,1 D_a^{1,25}$ . Für No. 62 findet man (Reihe 9)  $D_a = 0,724$  und (Reihe 15) den Korrektionsfaktor = 119 %, mithin

$$F = 1,19 \times 18,1 \times (0,724)^{1,25} = 14,4 \text{ kg/mm}^2$$

Die angewandten Prüfungsmethoden entsprechen der Standard Prüfung D143-24T der American Society for Testing Materials, wie es in *Proc. A. S. T. M.* 939; 24 (*cf.* U. S. Dep. Agr. *Bull.* 556) mitgeteilt wird. Die hauptsächlichsten Angaben, die den Vorgang bei jeder besonderen Prüfung bezeichnen, sind zusammengestellt, die folgenden:

**Volumabnahme (Schwindung).**—Muster  $5,08 \times 5,08 \times 15,24$  cm. Das Volumen wurde in unausgetrocknetem Zustande und dann nach der Trocknung im Ofen bei  $100^\circ\text{C}$ , bis zum konstantem Gewicht bestimmt. Die Proben waren vor der Ofentrocknung vollständig lufttrocken.

**Volumabnahme, tangential und radial.**—Muster  $2,54 \times 10,16 \times 2,54$  cm. Die Masse sind im ungetrocknetem Zustande abgenommen und dann nach der Ofentrocknung bei  $100^\circ\text{C}$ , bis zum konstantem Gewicht bestimmt. Die Proben waren vor der Ofentrocknung vollständig lufttrocken.

**Statischer Biegeversuch.**—Muster  $5,08 \times 5,08 \times 76,20$  cm, Mittelbelastung, 71,12 cm Spannweite, Belastung durch eine Festigkeitsmaschine, derart, dass die Durchbiegung 0,254 cm in der Minute beträgt. Die gesamt Arbeit ist diejenige, die bei

I valori qui riportati per certi legni dell'America del Nord sono il risultato di una estesa serie di prove eseguite sopra un piccolo numero di specie senza difetti. Tutti i saggi sono stati condotti con lo stesso metodo, per modo che i risultati sono strettamente confrontabili. L'esame dei valori numerici ha permesso di stabilire alcune relazioni fra densità e resistenza, le quali sono rappresentate dalle equazioni riprodotte nella prima parte della tabella (Tabella 1). Queste equazioni sono tutte di tipo parabolico, e il grado è determinato con l'approssimazione del quarto dell'unità.

Introducendo nell'equazione per una data proprietà il peso specifico di una determinata specie (colonne 8 e 9) si ottiene il valore della proprietà corrispondente.

In molte specie la media dei risultati dei saggi scarta notevolmente dai valori che si ottengono dall'equazione generale; solo in poche però, tutti i valori sono sempre al di sopra e sempre al di sotto dei normali.

Siccome lo scarto di una proprietà dal valore risultante dall'equazione sta spesso ad indicare se una specie è adatta o no ad uno speciale impiego, è necessario completare le equazioni con dei fattori di correzione per le proprietà di ogni specie. Questi fattori, espressi in percento, sono riportati sotto le equazioni corrispondenti e costituiscono la seconda parte della Tabella 1. Moltiplicando il valore  $F$  dato dall'equazione per il rispettivo fattore di correzione, si ottengono valori medi esatti per la proprietà del campione in questione.

**Esempio:** Si debba trovare la resistenza alla rottura dello "shagbark hickory" seccato all'aria. Dall'elenco di riferimento si ricava che si tratta del No. 62, *Hicoria ovata*. Dall'equazione della colonna 15 si ha  $F = 18,1 D_a^{1,25}$ . Per il No. 62 si trova  $D_a = 0,724$  (colonna 9) e come fattore di correzione 119 % (colonna 15), per modo che si ha

$$F = 1,19 \times 18,1 \times (0,724)^{1,25} = 14,4 \text{ kg/mm}^2$$

I metodi di prova adoperati corrispondono alle norme D143-24T della American Society for Testing Materials, quali si trovano indicate nei *Proc. A. S. T. M.* 939; 24 (*v.* U. S. Dep. Agr. *Bull.* 556). Le indicazioni principali riferentisi a ogni specie di saggio sono le seguenti:

**Contrazione di volume.**—Dimensioni della provetta  $5,08 \times 5,08 \times 15,24$  cm. Il volume viene determinato su legno non stagionato e su legno seccato in forno a  $100^\circ\text{C}$  fino a costanza di peso. I provini vengono seccati completamente all'aria prima che nel forno.

**Diminuzione di volume, tangenziale e radiale.**—Dimensioni della provetta  $2,54 \times 10,16 \times 2,54$  cm. La larghezza viene misurata su legno non stagionato e su legno seccato in forno a  $100^\circ\text{C}$  fino a costanza di peso. Le provette vengono seccate completamente all'aria prima che nel forno.

**Flessione statica.**—Dimensioni della provetta  $5,08 \times 5,08 \times 76,20$  cm. Carico centrale, distanza tra gli appoggi 71,12 cm. Il carico viene applicato con una macchina di prova in modo che la freccia di incurvamento cresca con la velocità di 0,254 cm al minuto. Il lavoro totale è quello che si ottiene prolungando il saggio finchè o si raggiunge una freccia di 15,24 cm o il carico si abbassa a 90,7 kg o meno.

**Compression Perpendicular to Grain.**—Specimen  $5.08 \times 5.08 \times 15.24$  em ( $2 \times 2 \times 6$  in.). Load applied to side through a steel plate  $5.08$  em ( $2$  in.) wide laid across center of piece and at right angles to its length,  $\frac{1}{3}$  of surface being thus directly subjected to compression; testing machine head moving  $0.061$  em ( $0.024$  in.) per min.

**Shear Parallel to Grain.**—Specimen  $5.08 \times 5.08 \times 6.35$  em ( $2 \times 2 \times 2.5$  in.). Undercut at one end to permit shear over area  $5.08 \times 5.08$  em ( $2 \times 2$  in.); testing machine head moving  $0.038$  em ( $0.015$  in.) per min.

**Tension Perpendicular to Grain.**—Specimen as above. Transverse recess bored at each end to permit gripping for tension over  $5.08 \times 2.54$  em ( $2 \times 1$  in.) area; testing machine head moving  $0.635$  em ( $0.25$  in.) per min.

**Hardness.**—Specimen  $5.08 \times 5.08 \times 15.24$  em ( $2 \times 2 \times 6$  in.). Load required to embed a steel ball having a maximum cross-sectional area of  $1$  em<sup>2</sup> to  $\frac{1}{2}$  its diam.; testing machine head moving  $0.635$  em ( $0.25$  in.) per minute.

**Cleavage Parallel to Grain.**—Specimen  $5.08 \times 5.08 \times 9.525$  em ( $2 \times 2 \times 3\frac{3}{4}$  in.). Transverse recess bored at one end to permit gripping for cleavage of specimen over  $5.08$  em ( $2$  in.) width and along a  $7.62$  em ( $3$  in.) length; testing machine head moving  $0.635$  em ( $0.25$  in.) per min.

#### CONVERSION FACTORS

Multiply	By	To obtain
Kg per mm <sup>2</sup> .....	1422	lb. per in. <sup>2</sup>
Kg-mm per mm <sup>3</sup> .....	1422	in.-lb. per in. <sup>3</sup>
Meters.....	39.37	in.
Kg.....	2.205	lb.
Kg per mm of width.....	56	lb. per in. of width

### WOODS OF THE PHILIPPINE ISLANDS

THE BUREAU OF FORESTRY AND THE BUREAU OF SCIENCE OF THE  
PHILIPPINE ISLANDS

#### Introduction

Density and strength values for five woods of commerce have been determined. The testing methods used and manner of displaying the results are identical with those used by the U. S. Forest Products Laboratory and the results have therefore been incorporated at the end of Table 1 below.

#### CANADIAN WOODS

A number of the species listed in Table 1 below have also been tested by the Canadian Forest Products Laboratory, using samples obtained from trees grown in Canada. As far as can be definitely determined, these woods are substantially the same in properties as like species grown in the United States.

**Essai de flexion par choc.**—Eprouvette et portée comme ci-dessus. Un marteau de  $22,7$  kg ( $50$  lb.) tombe premièrement d'une hauteur de  $2,54$  em ( $1$  pouce), ensuite de  $5,08$  em ( $2$  pouces) de haut, etc., jusqu'à  $25,4$  em ( $10$  pouces), ensuite par augmentations successives de hauteur de  $5,08$  em ( $2$  pouces) jusqu'à rupture.

**Compression parallèle à la fibre.**—Eprouvette  $5,08 \times 5,08 \times 20,32$  em ( $2 \times 2 \times 8$  pouces). Charge finale, machine à essai dont la pièce mobile se déplace de  $0,061$  em par minute.

**Compression perpendiculaire à la fibre.**—Eprouvette  $5,08 \times 5,08 \times 15,24$  em ( $2 \times 2 \times 6$  pouces). Charge appliquée sur le côté par l'intermédiaire d'une plaque d'acier de  $5,08$  em de largeur disposée au milieu de la pièce et normalement à sa longueur, de façon que  $\frac{1}{3}$  de la surface soit soumis à la compression; machine à essai dont la pièce mobile se déplace de  $0,061$  em ( $0,024$  pouce) par minute.

**Cisaillement parallèle à la fibre.**—Eprouvette  $5,08 \times 5,08 \times 6,35$  em ( $2 \times 2 \times 2\frac{1}{2}$  pouce). Entaillée à une extrémité pour permettre le cisaillement sur une surface de  $5,08 \times 5,08$  em ( $2 \times 2$  pouces); machine à essai dont la pièce mobile se déplace de  $0,038$  em ( $0,015$  pouce) par minute.

**Traction perpendiculaire à la fibre.**—Eprouvette comme ci-dessus. Niche transversale découpée à chaque extrémité de façon à permettre la traction sur une surface de  $5,08 \times 2,54$  em ( $2 \times 1$  pouce). Machine à essai dont la pièce mobile se déplace de  $0,635$  em ( $0,25$  pouce) par minute.

**Dureté.**—Eprouvette  $5,08 \times 5,08 \times 15,24$  em ( $2 \times 2 \times 6$  pouces). Charge nécessaire pour enfoncer une bille d'acier ayant une section maximum de  $1$  em<sup>2</sup>, de la moitié de son diamètre. Machine à essai dont la pièce mobile se déplace de  $0,635$  em ( $0,25$  pouce) par minute.

**Clivage parallèle à la fibre.**—Eprouvette  $5,08 \times 5,08 \times 9,525$  em ( $2 \times 2 \times 3\frac{3}{4}$  pouces). Niche transversale découpée à une extrémité de façon à permettre le clivage de l'éprouvette sur une largeur de  $5,08$  em ( $2$  pouces) et le long de  $7,62$  em ( $3$  pouces); machine à essai dont la pièce mobile se déplace de  $0,635$  em ( $0,25$  pouce) par minute.

### BOIS DES ÎLES PHILIPPINES

BUREAU DE SYLVICULTURE ET BUREAU DE SCIENCE DES ÎLES  
PHILIPPINES

#### Introduction

Les valeurs de densité et de résistance ont été déterminées pour cinq bois du commerce. Les méthodes d'essais utilisées, et la façon de disposer les résultats sont identiques à celles utilisées par le U. S. Forest Products Laboratory (voir ci-dessus); c'est pourquoi les résultats ont été incorporés à la fin de la Table 1.

#### BOIS CANADIENS

Un certain nombre d'espèces mentionnées au bas de la Table 1 ont aussi été essayées par le "Laboratoire des Produits Forestiers Canadiens" qui employa des échantillons provenant d'arbres ayant poussé au Canada. Pour autant qu'on peut le déterminer d'une façon définie, ces bois sont les mêmes, au point de vue de leurs propriétés, que ceux des mêmes espèces croissant aux États-Unis.



fortgesetzter Prüfung entweder eine 15,24 cm Durchbiegung erreicht, oder das Gewicht fällt auf 90,7 kg oder weniger.

**Schlagbiegeversuch.**—Muster und Grösse wie oben. Ein 22,7 kg Hammer fällt zuerst von 2,54 cm dann von 5,08 cm u. s. w. Höhe herunter, bis 25,4 cm, von hier an, in Höhenzunahmen um 5,08 cm bis zum Bruch.

**Druckversuch parallel zur Faserrichtung.**—Muster  $5,08 \times 5,08 \times 20,32$  cm. Endlast, Festigkeitsmaschine derart, dass Zusammendrücken in der Minute 0,061 cm beträgt.

**Druck senkrecht zur Faserrichtung.**—Muster  $5,08 \times 5,08 \times 15,24$  cm. Das Gewicht an die Seite drückt auf eine Stahlplatte von 5,08 cm Weite, die um die Mitte des Stückes in rechten Winkeln zu seiner Länge angelegt ist, wodurch  $\frac{1}{2}$  der Oberfläche dem Drucke ausgesetzt wird, derart, dass die Zusammendrückung 0,061 cm in der Minute beträgt.

**Scherversuch, parallel zur Faserrichtung.**—Muster  $5,08 \times 5,08 \times 6,35$  cm. An einem Ende unterschritten, um eine Scherung über eine Fläche von  $5,08 \times 5,08$  cm zu gestatten; Scherung 0,038 cm in der Minute.

**Zugversuch senkrecht zur Faserrichtung.**—Muster so wie oben. Kreuzweise an jedem Ende gebohrt um die Zugkraft auf eine Fläche von  $5,08 \times 2,54$  cm wirken zu lassen. Zug der Maschine 0,635 cm in der Minute.

**Härte.**—Muster  $5,08 \times 5,08 \times 15,24$  cm. Das notwendige Gewicht um eine Stahlkugel von einem maximalen Querschnitt von 1 cm bis zur Hälfte seines Durchmessers einzudrücken. Bewegung der Maschine 0,635 cm in der Minute.

**Spaltung parallel zur Faserrichtung.**—Muster  $5,08 \times 5,08 \times 9,525$  cm. Kreuzweise an einem Ende gebohrt für die Fassung des Musters zur Spaltung über eine Weite von 5,08 cm und 7,62 cm der Länge nach. Spaltung 0,635 cm in der Minute.

## HÖLZER DER PHILIPPINEN

THE BUREAU OF FORESTRY AND THE BUREAU OF SCIENCE OF THE  
PHILIPPINE ISLANDS

### Einleitung

Dichte und Festigkeit von fünf Hölzern des Handels sind bestimmt worden. Die angewendeten Prüfungsmethoden und der Vorgang bei der Darstellung der Ergebnisse sind dieselben, welche von U. S. Forest Products Laboratory angewandt werden und schon oben verzeichnet sind. Es sind daher die Ergebnisse am Ende der Tafel 1 (unten) angegeben.

## CANADISCHE HÖLZER

Eine Anzahl der in der Liste Tabelle 1 unten vorhandenen Arten sind ebenso vom Canadian Forest Products Laboratory untersucht worden, indem Proben von in Canada gewachsenen Bäumen, verwendet wurden. Soweit man ein abschliessendes Urteil abgeben kann, sind diese Hölzer im wesentlichen von gleicher Eigenschaft wie diejenigen, die in den Vereinigten Staaten gewachsen sind.

**Flessione per urto.**—Dimensioni come sopra. Un martello di 22,7 kg cade prima di una altezza di 2,54 cm, poi di 5,08 cm ecc. fino a 25,4 cm; da 25,4 in poi l'aumento di altezza è di 5,08 cm fino a rottura.

**Compressione parallela alla fibra.**—Dimensioni della provetta,  $5,08 \times 5,08 \times 20,32$  cm. Carico finale, spostamento della macchina 0,061 cm al minuto.

**Compressione perpendicolare alla fibra.**—Dimensioni della provetta  $5,08 \times 5,08 \times 15,24$  cm. Il carico è applicato lateralmente a mezzo di una piastra di acciaio di 5,08 cm di larghezza, e questa è disposta nel mezzo del pezzo ad angolo retto rispetto alla lunghezza, per modo che  $\frac{1}{2}$  della superficie viene sottoposta a pressione. Lo spostamento della macchina deve essere di 0,061 cm al minuto.

**Taglio nel senso della fibra.**—Dimensioni della provetta  $5,08 \times 5,08 \times 6,35$  cm. Adattato ad una estremità in maniera da permettere il taglio sopra un'area di  $5,08 \times 5,08$  cm. Spostamento della macchina 0,038 cm al minuto.

**Trazione perpendicolare al senso della fibra.**—Dimensioni come sopra. Forato in croce ad ogni estremità per fare agire lo sforzo sopra una superficie di  $5,08 \times 2,54$  cm. Spostamento della macchina 0,635 cm al minuto.

**Durezza.**—Dimensioni della provetta,  $5,08 \times 5,08 \times 15,24$  cm. Carico necessario per far penetrare fino a metà spessore una sfera di acciaio avente una sezione massima di 1 cm.<sup>2</sup> Spostamento della macchina 0,635 cm al minuto.

**Sfaldatura parallela alla fibra.**—Dimensioni delle provette  $5,08 \times 5,08 \times 9,525$ . Forato a croce ad una estremità per sollecitare la provetta allo scorrimento per una larghezza di 5,08 cm e una lunghezza di 7,62 cm. Spostamento della macchina 0,635 cm al minuto.

## LEGNI DELLE FILIPPINE

THE BUREAU OF FORESTRY AND THE BUREAU OF SCIENCE OF THE  
PHILIPPINE ISLANDS

### Introduzione

Sono state determinate densità e tenacità di cinque legni del commercio. I metodi di saggio adoperati e la rappresentazione dei risultati sono gli stessi impiegati dall' U. S. Forest Products Laboratory (v. sopra). I risultati sono stati perciò incorporati nella Tabella 1 e riportati in fondo.

## LEGNI DEL CANADÀ

Un certo numero delle specie elencate nella Tabella 1 in basso è stato esaminato dal Canadian Forest Products Laboratory, il quale ha eseguito i saggi su campioni di alberi cresciuti nel Canada. Questi legni hanno dimostrato di possedere proprietà eguali a quelle delle stesse specie crescenti negli Stati Uniti.

TABLE 1.—STRENGTH AND RELATED PROPER-

Index No.	Botanical name		Common name	Place of growth of material tested *	Seasoning condition	Density based on weight when oven-dry and volume			Moisture content
	Family	Genus and species				When oven-dry $D_o$	When green ( $D_g$ )	When air-dry ( $D_d$ )	
						g/cm <sup>3</sup>			% of oven dry-weight

## I. Equations expressing strength proper-

1	2	3	4	5	6	7	8	9	10
Green .....									
Green to oven-dry .....									
Air-dry .....									

## II. Values as determined by tests—strength and shrink-

1	<i>Aceraceae</i>	<i>Acer macrophyllum</i>	Maple, bigleaf	Washington	Green	0.513	0.440		72
					Air-dry			0.483	12
2		<i>Acer nigrum</i>	Maple, black	Indiana	Green	0.620	0.520		65
					Air-dry			0.568	12
3		<i>Acer pennsylvanicum</i>	Maple, striped	Vermont	Green		0.438		35
					Air-dry			0.464	12
4		<i>Acer rubrum</i>	Maple, red	Wisconsin, Pennsylvania, New Hampshire	Green	0.546	0.488		63
					Air-dry			0.538	12
5		<i>Acer saccharinum</i>	Maple, silver	Wisconsin	Green	0.506	0.439		66
					Air-dry			0.470	12
6		<i>Acer saccharum</i>	Maple, sugar	Ind., Pa., Vt., Wis.	Green	0.676	0.568		57
					Air-dry			0.630	12
7	<i>Anacardiaceae</i>	<i>Rhus hirta</i>	Sumach, staghorn	Wisconsin	Green		0.449		45
					Air-dry			0.473	12
8		<i>Rhus metopium</i>	Poisonwood	Florida	Green	0.553	0.511		71
					Air-dry			0.533	12
9	<i>Aquifoliaceae</i>	<i>Ilex opaca</i>	Holly	Tennessee	Green	0.606	0.503		82
					Air-dry			0.569	12
10	<i>Betulaceae</i>	<i>Alnus rubra</i>	Alder, red	Washington	Green	0.434	0.368		98
					Air-dry			0.407	12
11		<i>Betula alaskana</i>	Birch, Alaska	Alaska	Green	0.594	0.488		58
					Air-dry				
12		<i>Betula lenta</i>	Birch, sweet	Pennsylvania	Green	0.714	0.601		53
				New Hampshire	Air-dry			0.654	12
13		<i>Betula lutea</i>	Birch, yellow	Wis., Pa.	Green	0.668	0.550		68
					Air-dry			0.617	12
14		<i>Betula papyrifera</i>	Birch, paper	Wis., N. H.	Green	0.600	0.484		65
					Air-dry			0.552	12
15		<i>Betula populifolia</i>	Birch, gray	New Hampshire	Green	0.552	0.448		63
					Air-dry			0.506	12
16		<i>Carpinus caroliniana</i>	Beech, blue	Massachusetts	Green	0.717	0.575		48
					Air-dry			0.694	12
17		<i>Ostrya virginiana</i>	Hornbeam	Wisconsin	Green	0.762	0.632		52
					Air-dry			0.708	12
18	<i>Burseraceae</i>	<i>Bursera simaruba</i>	Gumbo, limbo	Florida	Green	0.320	0.305		99
					Air-dry			0.307	12
19	<i>Caprifoliaceae</i>	<i>Sambucus glauca</i>	Elderberry, blue	Oregon	Green	0.570	0.464		124
					Air-dry			0.518	12
20	<i>Combretaceae</i>	<i>Conocarpus erecta</i>	Buttonwood, Florida	Florida	Green	0.851	0.694		47
					Air-dry			0.709	12

\*All material tested was grown in the United States. The State or States in which grown are listed in column 5.



Shrinkage from green to oven-dry condition			Static bending					Impact bending 22.7 kg hammer			Compression parallel to grain			Compression perpendicular to grain	Shear		Tension perpendicular to grain		Hardness: load to embed a steel ball of 1 sq. cm maximum cross section to one-half its diameter			Cleavage		
In volume	Radial	Tangential	Fiber stress at elastic limit	Modulus of rupture	Modulus of elasticity	Work to elastic limit	Work to maximum load	Total work	Fiber stress at elastic limit	Modulus of elasticity	Work to elastic limit	Height of drop causing complete failure	Fiber stress at elastic limit		Maximum crushing strength	Modulus of elasticity	Radial	Tangential	Radial	Tangential	End	Radial	Tangential	Radial
% of dimension when green	kg/mm <sup>2</sup>			kg-mm/mm <sup>3</sup>			kg/mm <sup>2</sup>	kg-mm/mm <sup>3</sup>	m	kg/mm <sup>2</sup>			kg/mm <sup>2</sup>	kg/mm <sup>2</sup>	kg/mm <sup>2</sup>	kg/mm <sup>2</sup>	kg	kg/mm of width						

11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
$S = 26.5D_0^{1.00}$	$S = 9.10D_0^{1.00}$	$S = 16.3D_0^{1.00}$	$F = 11.74D_d^{1.25}$	$F = 18.1D_d^{1.25}$	$F = 1969D_d^{1.00}$	$F = 0.00389D_d^{1.50}$	$F = 0.0228D_d^{1.75}$	$F = 0.0511D_d^{2.00}$	$F = 21.9D_d^{1.25}$	$F = 2380D_d^{1.00}$	$F = 0.0112D_d^{1.50}$	$F = 2.40D_d^{1.75}$	$F = 6.15D_d^{1.00}$	$F = 8.58D_d^{1.00}$	$F = 2380D_d^{1.00}$	$F = 3.26D_d^{2.25}$	$F = 2.22D_d^{1.25}$	$F = 2.40D_d^{1.25}$	$F = 1.31D_d^{2.00}$	$F = 1.60D_d^{2.00}$	$F = 2180D_d^{2.25}$	$F = 1690D_d^{2.25}$	$F = 1750D_d^{2.25}$	$F = 20.4D_d^{2.00}$	$F = 22.9D_d^{2.00}$
			$F = 7.17D_0^{1.25}$	$F = 12.4D_0^{1.25}$	$F = 1660D_0^{1.00}$	$F = 0.00172D_0^{1.50}$	$F = 0.0250D_0^{1.75}$	$F = 0.0724D_0^{2.00}$	$F = 16.7D_0^{1.25}$	$F = 2070D_0^{1.00}$	$F = 0.00745D_0^{1.50}$	$F = 2.90D_0^{1.75}$	$F = 3.69D_0^{1.00}$	$F = 4.73D_0^{1.00}$	$F = 2050D_0^{1.00}$	$F = 2.11D_0^{2.25}$	$F = 1.73D_0^{1.25}$	$F = 1.85D_0^{1.25}$	$F = 1.27D_0^{2.00}$	$F = 1.62D_0^{2.00}$	$F = 1700D_0^{2.25}$	$F = 1530D_0^{2.25}$	$F = 1570D_0^{2.25}$	$F = 19.3D_0^{2.00}$	$F = 22.5D_0^{2.00}$

99	92	99	119	116	105	144	102	76	100	114	90	85	103	109	97	118	120	123	143	154	129	118	114	134	150
			99	104	108	141	87	68		98		107	122	103	87	104	123	145	101	120	147	120	115	125	158
101	102	109	90	101	108	77	112	117	96	99	95	132	104	93	88	107	97	103	118	136	109	112	101	128	140
			101	105	102	103	104	106	88	95	83	112	90	97	92	97	108	118	65	128	128	115	110	109	105
105			99	115	104	97	130	67	103	141	75	134	79	99	109	106	123	130			86	95			
			80	109	103	62	135	117	95	88	102	108		97		97		108			113	104			
101	89	102	92	107	120	78	113	97	101	103	101	97	95	100	123	85	101	107	126	119	105	104	100	100	106
			111	112	109	129	115	128	106	108	108	99	98	99	92	107	119	128	107	160	120	101	101	147	135
103	75	100	85	92	91	86	131	112	80	79	84	107	84	84	83	97	111	120	140	144	115	111	110	133	135
			98	90	87	111	95	90	103	84	137	99	108	93	70	110	114	127	83	131	133	99	106	122	131
99	92	99	101	108	115	99	100	109	104	106	104	95	105	105	102	95	106	116	110	123	102	102	98	110	119
			101	108	104	102	114	95	119	121	117	93	102	103	94	108	125	135	120	102	111	109	112	121	150
			80	90	76	92	123	204						89		97					109	107	103		
			123	102	91	167	97	119						106		121					100	105	91		
85	89	86	71	67	34	153	50	27	78	76	85	43	39	63	96	136	73	91	68	64	49	43	36	67	53
			71	91	86	59	59	31						74		72									
121	98	116	77	87	75	83	101	127	88	71	116	148	74	78	58	95	96	113	102	128	108	108	109	105	136
			75	81	70	83	89	64	82	72	101	93	71	83	60	89	94	118	123	85	107	95	100	99	
129	129	122	127	129	134	130	129	101	117	129	108	110	136	119	135	99	104	107	148	136	141	119	125	128	143
			130	119	120	133	125	74	115	115	117	102	130	120	143	90	97	109	102	140	156	117	125	130	136
128			90	98	117	72	113	136	101	103	103	113	77	92	96	73	84	92	48	33	74	85	80	67	59
98	118	87	88	100	116	83	107	116	83	114	64	102	85	92	127	62	90	94	58	59	90	87	90	71	

1	2	3	4	5	6	7	8	9	10
21	Cornaceae	<i>Cornus florida</i>	Dogwood (flowering)	Tennessee	Green	0.796	0.638		62
					Air-dry			0.735	12
22		<i>Cornus nuttallii</i>	Dogwood, Pacific	Oregon	Green	0.701	0.578		52
					Air-dry			0.644	12
23		<i>Nyssa aquatica</i>	Gum, tupelo	Louisiana, Missouri	Green	0.524	0.455		97
					Air-dry			0.496	12
24		<i>Nyssa sylvatica</i>	Gum, black	Tennessee	Green	0.552	0.462		55
					Air-dry			0.507	12
25	Ebenaceae	<i>Diospyros virginiana</i>	Persimmon	Missouri	Green	0.776	0.639		59
					Air-dry			0.748	12
26	Ericaceae	<i>Arbutus menziesii</i>	Madroña	Oregon, California	Green	0.694	0.575		69
					Air-dry			0.653	12
27		<i>Kalmia latifolia</i>	Laurel, mountain	Tennessee	Green	0.744	0.616		62
					Air-dry			0.684	12
28		<i>Oxydendrum arboreum</i>	Sourwood	Tennessee	Green	0.593	0.504		69
					Air-dry			0.550	12
29		<i>Rhododendron maximum</i>	Rhododendron, great	Tennessee	Green	0.601	0.501		99
					Air-dry			0.576	12
30	Fagaceae	<i>Castanea dentata</i>	Chestnut	Tennessee, Maryland	Green	0.454	0.396		122
					Air-dry			0.433	12
31		<i>Castanopsis chrysophylla</i>	Chinquapin, golden	Oregon	Green	0.483	0.417		134
					Air-dry			0.459	12
32		<i>Fagus grandifolia</i>	Beech	Ind., Pa.	Green	0.655	0.544		62
					Air-dry			0.624	12
33		<i>Quercus alba</i>	Oak, white	La., Ark., Ind.	Green	0.710	0.595		68
					Air-dry			0.683	12
34		<i>Quercus bicolor</i>	Oak, swamp white	Indiana	Green	0.792	0.637		74
					Air-dry			0.720	12
35		<i>Quercus borealis</i>	Oak, red	La., Ark., Ind., Tenn., N. H.	Green	0.657	0.564		80
					Air-dry			0.628	12
36		<i>Quercus californica</i>	Oak, California black	Oregon, California	Green	0.578	0.510		106
					Air-dry			0.571	12
37		<i>Quercus chrysolepis</i>	Oak, canyon live	California	Green	0.838	0.702		62
					Air-dry			0.778	12
38		<i>Quercus coccinea</i>	Oak, scarlet	Massachusetts	Green	0.709	0.603		65
					Air-dry				
39		<i>Quercus gambelii</i>	Oak, Gambel	Arizona	Green	0.701	0.617		61
					Air-dry			0.735	12
40		<i>Quercus garryana</i>	Oak, Oregon white	Oregon	Green	0.748	0.644		72
					Air-dry			0.724	12
41		<i>Quercus laurifolia</i>	Oak, laurel	Louisiana	Green	0.703	0.564		84
					Air-dry			0.632	12
42		<i>Quercus macrocarpa</i>	Oak, bur	Wisconsin	Green	0.671	0.583		70
					Air-dry			0.644	12
43		<i>Quercus montana</i>	Oak, chestnut	Tennessee	Green	0.674	0.573		72
					Air-dry			0.658	12
44		<i>Quercus nigra</i>	Oak, water	Louisiana	Green	0.685	0.556		81
					Air-dry			0.633	12
45		<i>Quercus rubra pagodaefolia</i>	Oak, swamp red	Louisiana	Green	0.708	0.607		78
					Air-dry			0.680	12
46		<i>Quercus palustris</i>	Oak, pin	Massachusetts	Green	0.677	0.577		75
					Air-dry				
47		<i>Quercus phellos</i>	Oak, willow	Louisiana	Green	0.688	0.556		94
					Air-dry			0.696	12
48		<i>Quercus prinus</i>	Oak, swamp chestnut	Louisiana	Green	0.756	0.595		76
					Air-dry			0.674	12
49		<i>Quercus rubra</i>	Oak, southern red	Louisiana	Green	0.624	0.521		90
					Air-dry			0.588	12
50		<i>Quercus stellata</i>	Oak, post	Arkansas, Louisiana	Green	0.738	0.596		69
					Air-dry			0.675	12
51		<i>Quercus velutina</i>	Oak, black	Arkansas, Wisconsin	Green	0.669	0.564		78
					Air-dry			0.610	12
52		<i>Quercus virginiana</i>	Oak, live	Florida	Green	0.977	0.810		50
					Air-dry			0.888	12
53	Hamamelidaceae	<i>Hamamelis virginiana</i>	Witch-hazel	Tennessee	Green	0.714	0.558		70
					Air-dry			0.614	12
54		<i>Liquidambar styraciflua</i>	Gum, red	Missouri	Green	0.530	0.441		81
					Air-dry			0.487	12
55	Hippocastanaceae	<i>Aesculus octandra</i>	Buckeye, yellow	Tennessee	Green	0.383	0.326		141
					Air-dry			0.363	12
56	Juglandaceae	<i>Hicoria alba</i>	Hickory, mockernut	Pa., Miss.	Green		0.642		60
					Air-dry			0.725	12
57		<i>Hicoria aquatica</i>	Hickory, water	Mississippi	Green		0.606		80
					Air-dry			0.621	12
58		<i>Hicoria cordiformis</i>	Hickory, bitternut	Ohio	Green		0.604		66
					Air-dry			0.663	12
59		<i>Hicoria glabra</i>	Hickory, pignut	W. Va., Miss., Ohio, Pa.	Green		0.661		54
					Air-dry			0.754	12
60		<i>Hicoria laciniosa</i>	Hickory, bigleaf shagbark	Ohio, Miss.	Green		0.622		61
					Air-dry			0.692	12
61		<i>Hicoria myristicifolia</i>	Hickory, nutmeg	Mississippi	Green		0.556		74
					Air-dry			0.605	12





1	2	3	4	5	6	7	8	9	10
62		<i>Hicoria ovata</i>	Hickory, shagbark	Miss., Ohio, W. Va., Pa.	Green		0.637		60
					Air-dry			0.724	12
63		<i>Hicoria pecan</i>	Hickory, pecan	Missouri	Green	0.694	0.601		63
					Air-dry			0.666	12
64		<i>Juglans cinerea</i>	Butternut	Wisconsin, Tennessee	Green	0.404	0.359		104
					Air-dry			0.383	12
65		<i>Juglans nigra</i>	Walnut, black	Kentucky	Green	0.562	0.513		81
					Air-dry			0.552	12
66		<i>Juglans rupestris</i>	Walnut, Mexican	Arizona	Green	0.613	0.532		67
					Air-dry			0.570	12
67	<i>Lauraceae</i>	<i>Sassafras sassafras</i>	Sassafras	Tennessee	Green	0.473	0.424		67
					Air-dry			0.451	12
68		<i>Umbellularia californica</i>	Myrtle, Oregon	Oregon	Green	0.589	0.512		71
					Air-dry			0.556	12
69	<i>Leguminosae</i>	<i>Gleditsia triacanthos</i>	Locust, honey	Indiana, Missouri	Green	0.666	0.596		63
					Air-dry			0.636	12
70		<i>Robinia pseudacacia</i>	Locust, black	Tennessee	Green	0.708	0.659		41
					Air-dry			0.694	12
71	<i>Magnoliaceae</i>	<i>Liriodendron tulipifera</i>	Poplar, yellow	Tennessee, Kentucky	Green	0.427	0.376		64
					Air-dry			0.401	12
72		<i>Magnolia acuminata</i>	Magnolia, cucumber	Tennessee	Green	0.516	0.440		80
					Air-dry			0.480	12
73		<i>Magnolia fraseri</i>	Magnolia, Fraser's	Tennessee	Green	0.477	0.400		89
					Air-dry			0.446	12
74		<i>Magnolia grandiflora</i>	Magnolia, evergreen	Louisiana	Green	0.530	0.460		117
					Air-dry			0.502	12
75	<i>Moraceae</i>	<i>Toxylon pomiferum</i>	Orange, osage	Indiana	Green	0.838	0.761		31
					Air-dry				
76		<i>Ficus aurea</i>	Fig, golden	Florida	Green		0.438		88
					Air-dry			0.444	12
77	<i>Myrtaceae</i>	<i>Eucalyptus globulus</i>	Gum, blue	California	Green	0.796	0.625		79
					Air-dry			0.750	12
78		<i>Eugenia garberi</i>	Stopper, Garber's	Florida	Green	0.918	0.831		40
					Air-dry			0.877	12
79	<i>Oleaceae</i>	<i>Fraxinus americana</i>	Ash, white	Ark., N. Y., W. Va.	Green	0.638	0.542		42
					Air-dry			0.593	12
80		<i>Fraxinus biltmoreana</i>	Ash, Biltmore white	Tennessee	Green	0.584	0.507		42
					Air-dry			0.550	12
81		<i>Fraxinus pennsylvanica lanceolata</i>	Ash, green	Louisiana, Missouri	Green	0.610	0.526		48
					Air-dry			0.566	12
82		<i>Fraxinus nigra</i>	Ash, black	Wisconsin, Michigan	Green	0.526	0.457		84
					Air-dry			0.493	12
83		<i>Fraxinus oregona</i>	Ash, Oregon	Oregon	Green	0.575	0.497		48
					Air-dry			0.550	12
84		<i>Fraxinus profunda</i>	Ash, pumpkin	Missouri	Green	0.551	0.485		51
					Air-dry			0.520	12
85		<i>Fraxinus quadrangulata</i>	Ash, blue	Kentucky	Green	0.603	0.532		39
					Air-dry			0.568	12
86	<i>Palmaceae</i>	<i>Sabal palmetto</i>	Palmetto, cabbage	Florida	Green	0.453	0.372		133
					Air-dry			0.387	12
87	<i>Pinaceae</i>	<i>Abies amabilis</i>	Fir, silver	Washington	Green	0.415	0.351		66
					Air-dry			0.385	12
88		<i>Abies balsamea</i>	Fir, balsam	Wisconsin	Green	0.414	0.335		117
					Air-dry			0.366	12
89		<i>Abies concolor</i>	Fir, white	California, New Mexico	Green	0.397	0.348		115
					Air-dry			0.371	12
90		<i>Abies grandis</i>	Fir, lowland white	Montana, Oregon	Green	0.419	0.370		94
					Air-dry			0.398	12
91		<i>Abies lasiocarpa</i>	Fir, alpine	Colorado	Green	0.321	0.306		47
					Air-dry			0.327	12
92		<i>Abies magnifica</i>	Fir, red	California	Green	0.421	0.372		108
					Air-dry			0.388	12
93		<i>Abies nobilis</i>	Fir, noble	Oregon	Green	0.403	0.351		36
					Air-dry			0.375	12
94		<i>Chamaecyparis lawsoniana</i>	Cedar, Port Orford	Oregon	Green	0.440	0.399		43
					Air-dry			0.416	12
95		<i>Chamaecyparis nootkatensis</i>	Cedar, Alaska	Oregon	Green	0.439	0.399		40
					Air-dry			0.422	12
96		<i>Chamaecyparis thyoides</i>	Cedar, southern white	New Hampshire, North Carolina	Green	0.352	0.310		35
					Air-dry			0.323	12
97		<i>Juniperus pachyphloea</i>	Juniper, alligator	Arizona	Green	0.545	0.477		40
					Air-dry			0.511	12
98		<i>Juniperus virginiana</i>	Cedar, eastern red	Vermont	Green	0.492	0.442		35
					Air-dry			0.471	12
99		<i>Larix laricina</i>	Tamarack	Wisconsin	Green	0.558	0.491		52
					Air-dry			0.528	12
100		<i>Larix occidentalis</i>	Larch, western	Montana, Washington	Green	0.587	0.482		58
					Air-dry			0.520	12
101		<i>Libocedrus decurrens</i>	Cedar, incense	Oregon, California	Green	0.365	0.346		108
					Air-dry			0.368	12





1	2	3	4	5	9	7	8	9	10
102		<i>Picea engelmanni</i>	Spruce, Engelmann	Colorado	Green	0.347	0.312		100
103		<i>Picea glauca</i>	Spruce, white	Wis., N. H.	Air-dry			0.332	12
104		<i>Picea mariana</i>	Spruce, black	New Hampshire	Green	0.431	0.366		50
105		<i>Picea rubra</i>	Spruce, red	Tennessee, New Hampshire	Air-dry			0.391	12
106		<i>Picea sitchensis</i>	Spruce, Sitka	Wash., Oregon	Green	0.428	0.376		38
107		<i>Pinus banksiana</i>	Pine, jack	Wisconsin	Air-dry			0.402	12
108		<i>Pinus caribaea</i>	Pine, slash	Florida	Green	0.413	0.379		43
109		<i>Pinus clausa</i>	Pine, sand	Florida	Air-dry			0.406	12
110		<i>Pinus contorta</i>	Pine, lodgepole	Wyo., Mont., Colo.	Green	0.397	0.355		44
111		<i>Pinus echinata</i>	Pine, shortleaf	Ark., La.	Air-dry			0.384	12
112		<i>Pinus edulis</i>	Piñon	Arizona	Green	0.461	0.394		105
113		<i>Pinus flexilis</i>	Pine, limber	New Mexico	Air-dry			0.428	12
114		<i>Pinus jeffreyi</i>	Pine, Jeffrey	California	Green	0.756	0.638		40
115		<i>Pinus lambertiana</i>	Pine, sugar	California	Air-dry			0.682	12
116		<i>Pinus monticola</i>	Pine, western white	Montana, Idaho	Green	0.506	0.451		36
117		<i>Pinus palustris</i>	Pine, longleaf	La., Miss., Fla.	Air-dry			0.481	12
118		<i>Pinus ponderosa</i>	Pine, western yellow	Colo., Wash., Ariz., Cal., Mont.	Green	0.434	0.380		65
119		<i>Pinus pungens</i>	Pine, mountain	Tennessee	Air-dry			0.410	12
120		<i>Pinus resinosa</i>	Pine, red	Wisconsin	Green	0.584	0.494		64
121		<i>Pinus rigida</i>	Pine, pitch	Tennessee	Air-dry			0.542	12
122		<i>Pinus rigida serotina</i>	Pine, pond	Florida	Green	0.567	0.502		63
123		<i>Pinus strobus</i>	Pine, eastern white	Wis., Minn., N. H.	Air-dry			0.530	12
124		<i>Pinus taeda</i>	Pine, loblolly	Florida	Green	0.420	0.374		68
125		<i>Pseudotsuga taxifolia</i>	Douglas fir (coast type)	Lewis Co., Chehalis Co., Clark Co., Wash.; Lane Co., Clatsop Co., Wash. Co., Ore.; Humboldt Co., Cal.	Air-dry			0.401	12
126		<i>Pseudotsuga taxifolia</i>	Douglas fir (mountain type)	Johnson Co., Wyo.; Missoula Co., Mont.	Green	0.425	0.371		101
127		<i>Sequoia sempervirens</i>	Redwood	California	Air-dry			0.402	12
128		<i>Taxodium distichum</i>	Cypress, southern	Louisiana, Missouri	Green	0.378	0.348		137
129		<i>Thuja occidentalis</i>	Cedar, northern white	Wisconsin	Air-dry			0.360	12
130		<i>Thuja plicata</i>	Cedar, western red	Montana, Washington	Green	0.418	0.363		54
131		<i>Tsuga canadensis</i>	Hemlock, eastern	Wis., Tenn., N. H.	Air-dry			0.385	12
132		<i>Tsuga heterophylla</i>	Hemlock, western	Washington, Oregon	Green	0.638	0.551		47
133		<i>Tsuga mertensiana</i>	Hemlock, mountain	Montana	Air-dry			0.592	12
134	Platanaceae	<i>Platanus occidentalis</i>	Sycamore	Indiana, Tennessee	Green	0.420	0.379		91
135	Polygonaceae	<i>Coccolobis laurifolia</i>	Plum, pigeon	Florida	Air-dry			0.402	12
136	Rhamnaceae	<i>Rhamnidium ferreum</i>	Ironwood, black	Florida	Green	0.549	0.494		75
137		<i>Rhamnus purshiana</i>	Cascara	Oregon	Air-dry			0.523	12
138	Rhizophoraceae	<i>Rhizophora mangle</i>	Mangrove	Florida	Green	0.507	0.440		54
139	Rosaceae	<i>Amelanchier canadensis</i>	Serviceberry	Tennessee	Air-dry			0.479	12
140		<i>Crataegus tomentosa</i>	Haw, pear	Wisconsin	Green	0.542	0.470		85
141		<i>Prunus pennsylvanica</i>	Cherry, wild red	Tennessee	Air-dry			0.505	12
					Green	0.580	0.501		56
					Air-dry			0.539	12
					Green	0.373	0.344		68
					Air-dry			0.362	12
					Green	0.593	0.504		72
					Air-dry			0.550	12
					Green	0.512	0.448		36
					Air-dry			0.482	12
					Green	0.446	0.405		39
					Air-dry			0.426	12
					Green	0.436	0.410		113
					Air-dry			0.427	12
					Green	0.482	0.425		91
					Air-dry			0.458	12
					Green	0.315	0.293		55
					Air-dry			0.310	12
					Green	0.344	0.310		39
					Air-dry			0.330	12
					Green	0.431	0.375		110
					Air-dry			0.398	12
					Green	0.432	0.377		77
					Air-dry			0.406	12
					Green	0.480	0.418		70
					Air-dry			0.450	12
					Green	0.539	0.456		83
					Air-dry			0.494	12
					Green	0.851	0.771		52
					Air-dry			0.786	12
					Green	1.077	1.045		32
					Air-dry			1.147	12
					Green	0.548	0.496		61
					Air-dry			0.516	12
					Green	1.063	0.886		39
					Air-dry			0.964	12
					Green	0.791	0.656		48
					Air-dry			0.747	12
					Green		0.623		63
					Air-dry			0.680	12
					Green	0.425	0.361		46
					Air-dry			0.394	12





1	2	3	4	5	6	7	8	9	10
142		<i>Prunus serotina</i>	Cherry, black	Pennsylvania	Green	0.534	0.471		55
					Air-dry			0.506	12
143		<i>Pyrus malus</i>	Applewood or wild apple	Virginia	Green	0.745	0.606		47
					Air-dry			0.668	12
144	<i>Salicaceae</i>	<i>Populus balsamifera</i>	Poplar, balsam	Vermont	Green	0.331	0.301		121
					Air-dry			0.316	12
145		<i>Populus deltoides</i>	Cottonwood, eastern	Missouri	Green	0.433	0.372		111
					Air-dry			0.408	12
146		<i>Populus grandidentata</i>	Aspen, large tooth	Wisconsin, Vermont	Green	0.412	0.348		99
					Air-dry			0.386	12
147		<i>Populus tremuloides</i>	Aspen	Wisconsin, New Mexico	Green	0.401	0.351		94
					Air-dry			0.380	12
148		<i>Populus trichocarpa</i>	Cottonwood, black	Washington	Green	0.368	0.315		132
					Air-dry			0.348	12
149		<i>Salix lasiandra</i>	Willow, western black	Oregon	Green	0.473	0.394		105
					Air-dry			0.441	12
150		<i>Salix nigra</i>	Willow, black	Wisconsin, Missouri	Green	0.408	0.338		139
					Air-dry			0.372	12
151	<i>Sapindaceae</i>	<i>Erothea paniculata</i>	Inkwood	Florida	Green	0.917	0.731		56
					Air-dry			0.800	12
152	<i>Sapotaceae</i>	<i>Dipholis salicifolia</i>	Bustie	Florida	Green		0.861		44
					Air-dry			0.885	12
153		<i>Sideroxylon mastichodendron</i>	Mastic	Florida	Green	1.034	0.886		39
					Air-dry			0.932	12
154	<i>Simaroubaceae</i>	<i>Simarouba glauca</i>	Paradise-tree	Florida	Green	0.359	0.332		81
					Air-dry			0.345	12
155	<i>Styracaceae</i>	<i>Mohrodendron carolinum</i>	Silverbell-tree	Tennessee	Green	0.475	0.418		70
					Air-dry			0.453	12
156	<i>Taxaceae</i>	<i>Taxus brevifolia</i>	Yew, Pacific	Washington	Green	0.673	0.601		44
					Air-dry			0.626	12
157	<i>Tiliaceae</i>	<i>Tilia glabra</i>	Basswood	Wisconsin, Pennsylvania	Green	0.398	0.325		103
					Air-dry			0.368	12
158	<i>Ulmaceae</i>	<i>Celtis laevigata</i>	Sugarberry	Missouri	Green	0.545	0.473		62
					Air-dry			0.515	12
159		<i>Celtis occidentalis</i>	Hackberry	Indiana, Wisconsin	Green	0.558	0.486		65
					Air-dry			0.531	12
160		<i>Ulmus americana</i>	Elm, American	Wisconsin, Pennsylvania, New Hampshire	Green	0.554	0.458		89
					Air-dry			0.507	12
161		<i>Ulmus fulva</i>	Elm, slippery	Indiana, Wisconsin	Green	0.568	0.485		85
					Air-dry			0.528	12
162		<i>Ulmus racemosa</i>	Elm, rock	Wisconsin	Green	0.658	0.574		49
					Air-dry			0.634	12
163	<i>Verbenaceae</i>	<i>Avicennia nitida</i>	Blackwood	Florida	Green	0.963	0.830		42
					Air-dry			0.830	12

TABLE 1A.—STRENGTH AND RELATED PROPERTIES OF  
I. Equations expressing strength properties

1	2	3	4	5	6	7	8	9	10	11	12	13	14
													$F = 12.08D_a^{1.25}$

II. Values as determined by tests—strength values

170	<i>Dipterocarpaceae</i>	<i>Dipterocarpus grandiflorus</i>	Apitong	P. I.	<i>d</i>	0.687							97
171		<i>Pentacme contorta</i>	White Lauan	P. I.	<i>d</i>	0.485							112
172		<i>Shorea negrosensis</i>	Red Lauan	P. I.	<i>d</i>	0.523							89
173		<i>Shorea polysperma</i>	Tangile	P. I.	<i>d</i>	0.538							102
174	<i>Sterculiaceae</i>	<i>Tarrietia javanica</i>	Lumbayau	P. I.	<i>d</i>	0.571							95



11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
92	86	92	104	116	117	101	135	136	109	106	117	108	118	112	112	81	112	115	120	130	110	111	101	122	130
			128	114	105	166	115	77	103	110	95	101	142	118	110	87	115	132	107	105	146	110	128	125	96
109	102	102	66	78	73	65	106	78	60	65	60	69	62	73	98	88	120	120	117	122	86	100	97	112	108
			66	82	68	76	146	95	84	66	91	91	54	75	115	71	92	84	81		112	117	112	102	
100			93	102	112	80	97	91	116	108	126	129	75	85	103	78	89	95	96	100	105	111	110	132	129
			98	111	115	94	132	104	104	115	100	113	105	99	104	111	103	113	162	150	112	102	123	160	170
142	115	151	96	102	115	89	116	124	103	117	96	103	90	90	118	75	87	96	149	139	95	93	94	133	139
			108	104	121	103	110	187	71	99	57	99	99	102	101	80	82	94	147	184	93	89	86	125	149
127	103	139	106	114	136	88	100	105	116	123	113	102	104	106	124	91	103	112	133	120	115	115	118	136	131
			110	116	131	97	126	119	120	119	127	126	116	114	123	104	105	113	132	120	112	96	94	117	126
124	109	116	114	107	103	135	112	100	107	100	123	123	89	90	106	79	95	96	101	84	79	93	93	99	88
			115	112	112	122	130	122	97	108	93	122	98	94	114	90	89	90	113	68	97	85	80	116	123
148	124	165	118	116	144	102	106	122	121	129	116	132	107	102	124	92	97	103	129	138	100	100	100	133	156
			120	123	129	113	131	127	118	121	115	145	120	106	113	89	119	113	115	144	124	102	101	147	150
131	81	141	97	102	110	97	154	155	103	115	96	147	87	88	117	91	104	113	112	111	107	122	117	121	111
			95	93	107	89	119	168	100	98	104	137	90	88	112	89	99	102	130	136	115	106	107	119	127
153	81	142	67	83	70	75	204	156	83	77	95	208	54	66	65	82	92	98	180	183	107	118	123	163	181
			82	84	70	116	137	103	86	77	106	114	63	78	66	99	112	115	162	157	108	111	110	148	193
97	100	91	104	90	89	124	78	116	95	88	102	76	84	91	93	108	101	102		71	72	85	86	82	63
			71	77	85	59	47	48				45	62	86	78	91	85	98		108	100	96			57
			68	84	91	51	63						83	92	90	79									
													58	89	100										
50	76	52	80	68	76	88	28	26	88	82	98	56	101	98	70	118	71	81	60	67	59	72	63	46	47
			43	43	68	28	21	11	49	72	34	28	45	61	64	71	36	61	34	42	51	46	54	30	38
98	73	96	74	78	89	85	35	21	90	87	95	44	71	81	103	106	121	100	150	123	112	82	89	130	101
			88	78	88	79	62	43	66	93	48	47	75	72	84	96	72	71	140	129	139	109	101		
113	100	112	102	109	118	94	113	103	113	114	109	95	100	102	102	110	108	126	130	106	99	97	97	133	140
			94	90	104	90	84	88	117	109	124	102	88	95	110	89	97	98	114	110	111	93	97	118	142
61	73	55	120	108	69	218	138	174	104	88	124	81	106	115	54	109	123	118	61	60	113	112	99	63	54
			101	107	78	133	131	101	70	72	69	74	81	108	59	135	120	132		47	123	139	108	43	42
184	220	176	107	114	134	93	105	95	105	111	102	104	100	101	136	89	96	100	122	131	96	92	89	118	121
			125	118	142	120	130	109	110	120	107	98	111	108	145	96	112	118	94	147	104	104	105	139	150
101	116	95	79	94	73	98	125	138	88	86	91	107	78	88	64	105	105	105	158	130	121	119	113	145	140
			88	90	80	113	110	128	86	79	95	120	90	93	69	124	90	92	138		122	120	109	113	119
107	109	111	70	90	83	70	144	150	81	78	86	148	80	81	66	83	103	104	135	123	102	104	102	129	120
			79	95	81	83	120	141	98	83	116	137	79	86	64	100	107	112	89	107	97	96	101	91	101
120	100	127	101	108	103	108	130	130	95	102	91	130	78	94	102	85	103	107	145	132	105	105	106	142	126
			107	109	95	130	132	154	103	90	121	134	93	90	83	88	113	108	137	115	109	101	105	122	109
111	111	113	97	112	108	99	152	182	95	96	94	145	111	101	93	87	113	102	151	118	102	99	98	146	128
			104	114	101	115	160	211	111	98	126	147	101	101	94	93	115	110	111	73	99	95	97	109	96
93	92	86	89	107	88	93	146	136	98	100	94	124	92	97	75	88	111	106	212	128	92	93	95	161	112
			85	103	87	91	130	154	95	92	99	131	86	93	94	94	103	106	90	95	89	100	97	77	99
71	83	71	68	80	79	63	48	55	84	85	84	50	81	88	74	95	72	64	58	38	64	74	78	36	33
			65	80	89	49	76	135						82		77									

CERTAIN WOODS OF THE PHILIPPINE ISLANDS  
of air-dry wood in terms of density

15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
$F = 20.90D_a^{1.25}$	$F = 2750D_a^{1.00}$	$F = 0.00416D_a^2$							$F = 7.38D_o^{1.25}$	$F = 8.37D_o^{1.00}$		$F = 2.71D_o^{2.25}$	$F = 2.17D_o^{1.33}$	$F = 2.17D_o^{1.33}$			$F = 1466D_o^{2.25}$	$F = 1365D_o^{2.25}$	$F = 1365D_o^{2.25}$		

expressed in percentage of equation values

95	102	98							103	109		84	99	99			87	89	89		
112	109	107	For other Philippine woods, see Bulletins							116	102	113	110	110			135	135	135		
85	85	90	Nos. 4 and 14, Bureau of Forestry, Philip-							106	99	92	108	108			95	96	96		
107	103	114	pine Islands 1907 and 1916.							96	96	109	98	98			108	106	106		
101	103	108							92	84		108	95	95			104	111	111		

## WOODS NATIVE TO

PHILIP

STRENGTH AND

For Canada, v. p. 4; for

Index No.	Botanical name		Local name	Place of growth	Seasoning condition	Bulk density	
	Family	Genus and species				Green	Air-dry
						g/cm <sup>3</sup>	
1	2	3	4	5	6	7	8
200	Aceraceae	<i>Acer pseudo-platanus</i> , Linn.	Sycamore	British Isles	Air-dry		
201	Anacardiaceae	<i>Campnosperma</i> sp.	Terentang	Fed. Malay States	Air-dry		0.348
202		<i>Euroschinus falcatus</i> , Hook., f.	Port Macquarie beech	Australia			0.433†
203		<i>Harpephyllum caffrum</i> , Bernh.	Kaffir plum, Zuurbesje, um-Gwenya, Mategibe	S. Africa			0.691†
204		<i>Mangifera indica</i> , Linn.	Am, Mango, Thayet	India			0.674†
205		<i>Melanorrhoea</i> ? sp.	Rengas	Fed. Malay States	Green	0.697	
206		<i>Protorhus longifolia</i> , Engl.	Red Cape beech, Rode Melkhout, um-Komiso	S. Africa			0.680†
207		<i>Rhus lucida</i> , Linn.	Taaibosch, in-Tlokoebomve, Manzi-mane	S. Africa			1.120†
208	Anonaceae	<i>Alphonsea ventricosa</i> , H., f. and Th.	Chooi	India			0.785†
209	Apocynaceae	<i>Dyera costulata</i> , Hook., f.	Jelutong	Fed. Malay States	Air-dry		0.369†
210		<i>Rauwolfia natalensis</i> , Sond.	Quinine tree, um-Hlambamasi	S. Africa			0.530†
211	Aquifoliaceae	<i>Ilex capensis</i> , Sond. and Harv.	Water tree, Wittehout, um-Duma	S. Africa			0.610†
212	Araliaceae	<i>Cussonia</i> sp.	Cabbage wood, um-Senge	S. Africa			0.460†
213		<i>Panax pinnatum</i> , A. Rich.	Mutati	E. Africa	Air-dry		0.360
214	Betulaceae	<i>Betula</i> spp.	Birch	British Isles	Air-dry		
215	Bombaceae	<i>Bombax insigne</i> , Wall.	Didu, Saitu, Semul	India			0.497†
216		<i>Coelostegia griffithii</i> , Benth.	Punggai	Fed. Malay States	Air-dry		0.537
217		<i>Cullenia excelsa</i> , Wight.	Karayani, Kabodda, Wild Durian	India	Green	0.492	
218	Boraginaceae	<i>Cordia platythyrsa</i> , Baker.	Pooli	W. Africa	Oven-dry		0.396†
219	Burseraceae	<i>Canarium australicum</i> , F. Muell.	Turpentine pine	Australia			0.644†
220		<i>Canarium bengalense</i> , Roxb.	Neribi	India			0.625†
221		<i>Canarium mauritianum</i> , Bl.	Colophane	Mauritius			0.813†
222		<i>Santiriopsis klaineana</i> , Pierre	Odonomokuku, incense tree	W. Africa			0.702†
223	Casuarinaceae	<i>Casuarina cunninghamii</i> , Miq.	River oak	New South Wales, Queensland			0.769†
224		<i>Casuarina decussata</i> , Benth.	Karri Shea-oak	W. Australia	Green	0.702	
225		<i>Casuarina equisetifolia</i> , Forst.	Beefwood, Ru, Chouk, Kabwi	India, Fed. Malay States, Queensland	Green	0.785	
226		<i>Casuarina fraseriana</i> , Miq.	Shea oak	W. Australia	Green	0.723	0.744
227		<i>Casuarina glauca</i> , Sieb.	Swamp oak	Australia	Green	0.852	0.930
228		<i>Casuarina torulosa</i> , Ait.	Forest oak	Australia			1.028†
229	Celastraceae	<i>Cathastrum capense</i> , Turcz.	Hard pear, coffee pear, um-Ngqangqa	S. Africa			0.900†
230		<i>Elaeodendron croceum</i> , DC.	Saffraanhout, saffronwood, um-Bomvana	S. Africa			0.894†
231		<i>Elaeodendron velutinum</i> , Harv.	um-Nqai, um-Ngayi	S. Africa			0.960†
232		<i>Pleurostylia wightii</i> , Wight and Arn.	Panaka, Pairi, Chiru-piyari	Ceylon			0.879†
233		<i>Pterocelastrus rostratus</i> , Walp.	White pearwood	S. Africa			0.686†
234		<i>Pterocelastrus variabilis</i> , Sond.	Candlewood, Kersehout, Itwyina	S. Africa			1.063†
235	Combretaceae	<i>Anogeissus acuminata</i> , Wall.	Yon, Chakwa, Panchi	India	Green	0.739	
236		<i>Anogeissus latifolia</i> , Wall.	Bakli, Dhaura	India	Green	0.793	
237		<i>Combretum kraussii</i> , Hochst.	Bush willow, Rodeblad, um-Dubuweklati	S. Africa			0.850†
238		<i>Terminalia bialata</i> , Wall.	Indian silver greywood, white Chuglam, Lein, Chugalam	India			0.769†
239		<i>Terminalia myriocarpa</i> , Huerck. and Muell. Arg.	Hollock, Panisaj, Sungloch, Shila	India			0.834†
240		<i>Terminalia paniculata</i> , Roth	Kindal, Kirijul	India			0.898†
241		<i>Terminalia procera</i> , Roxb.	Indian almond tree, Badam, Taree	India			0.593†

\* Tension parallel to grain.

† Bulk density calculated from weight and volume at time of test, no determination of moisture content having been made.



## THE BRITISH EMPIRE

HARRIS

RELATED PROPERTIES

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Bulk density		Static bending					Impact bending 22.68 kg hammer				Compression parallel to grain			Compression perpendicular to grain, fiber stress at elastic limit	Shear		Tension perpendicular to grain		Hardness			Lit.
Oven-dry	Moisture content	Fiber stress at elastic limit	Modulus of rupture	Modulus of elasticity	Work to elastic limit	Work to maximum load	Fiber stress at elastic limit	Modulus of elasticity	Work to elastic limit	Height of drop causing complete failure	Fiber stress at elastic limit	Maximum crushing strength	Modulus of elasticity		Radial	Tangential	Radial	Tangential	End	Radial	Tangential	
g/cm <sup>3</sup>	% oven-dry	kg/mm <sup>2</sup>		kg-cm/cm <sup>3</sup>			kg/mm <sup>2</sup>	kg-cm/cm <sup>3</sup>	cm		kg/mm <sup>2</sup>	kg/mm <sup>2</sup>	kg/mm <sup>2</sup>	kg/mm <sup>2</sup>	kg/mm <sup>2</sup>	kg/mm <sup>2</sup>	kg/mm <sup>2</sup>	kg/mm <sup>2</sup>	kg	kg	kg	
9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0.570		2.23	7.03	872								3.89										(5)
	16	2.25	4.18	788																		(21)
			3.54	881																		(61)
		4.57	8.40	1023	0.115							4.82										(12, 49)
			6.96	1037								6.19										(31, 43)
	45	4.50	9.61	1476																		(21)
		3.16	6.40	1085	0.054							4.41										(12)
		6.79	11.21	1253	0.197							9.78										(12)
			10.20	1234								5.79			1.083							(10, 43)
	17	2.60	4.38	717																		(21)
		2.67	4.91	726	0.054							4.54										(12)
		2.17	5.11	749	0.036							4.13										(12)
		2.34	2.86	548	0.049							2.67										(12)
	11		3.38									2.25			0.387							(22)
		4.75	9.78	1470								6.62										(5)
0.53-0.786			4.61	743								2.84			0.650							(10, 43)
																						(21)
	19	4.75	8.73	1476																		
	55	3.93	5.89	1002	0.089		8.51	1107	0.375	69	2.18	2.72	1173	0.475	0.520	0.573	0.316	0.418	333	306	284	(38)
0.554	8	5.73	9.34	1285	0.143		14.02	1747	0.612	74	3.76	5.28	1306	0.692	0.654	0.534	0.355	0.612	465	415	488	(38)
		5.03	7.54	813	0.176							4.22			0.783							(14)
			6.14	747																		(24)
			3.92	407								3.95			1.026							(10, 43)
		5.66	10.90	1272								5.69			0.988							(63)
		2.77	4.25	812								2.25			0.494							(57)
			10.13	1178																		(61)
	46	3.54	6.34	661								2.81			0.752		8.62*					(20)
	20	5.62	11.02	1589								6.68			1.58							(10, 21, 37)
	33	7.80	8.43	953											1.041		6.33*					(20)
	43	11.46	14.52	1668											0.816		11.95*					(20)
			11.38	1654								6.11	1432		1.047		11.59*					(2, 58, 59)
		3.52	6.41	761	0.091							5.54										(12)
		5.55	9.93	986	0.175							4.98			0.916							(55)
		5.16	10.82	1375	0.116							7.24										(12)
		5.32	9.11	1037	0.152							4.36			0.524							(54)
		3.74	10.93	999	0.078							4.77										(48)
		3.61	7.96	921	0.080							4.87			1.039							(55)
	35	5.63	9.24	1346	0.134		14.10	1950	0.572	112	3.08	4.62	1377	0.931	0.910	1.300	0.499	0.689	823	757	714	(41)
	35	4.47	8.51	1138	0.103		12.73	1467	0.613	144	2.16	3.83	1199	0.967	0.997	1.111	0.447	0.607	845	812	810	(31, 34, 41, 42)
																						(12)
		3.82	7.96	1038	0.084							5.13										
			11.52	1477								5.88			1.43							(10, 43)
			11.60									3.84			0.755							(9)
			7.43									4.62										(9)
			10.18	1098								6.52			1.032							(10, 43)

1	2	3	4	5	6	7	8
242		<i>Terminalia superba</i> , Engl. and Diels.	Afara, Afram	W. Africa	Air-dry		0.440
243		<i>Terminalia tomentosa</i> , W. and A.	Indian laurel wood, Taukkyan, Sain	India	Green	0.707	
					Air-dry		0.752
					Oven-dry		
244	<i>Compositae</i>	<i>Brachylaena discolor</i> , DC.	um-Pahla, Vaalbosch, Mapata	S. Africa		0.763	0.816
245		<i>Brachylaena hutchinsii</i> , Hutch.	Muhugu	E. Africa	Green	0.812	0.849
					Air-dry		
246	<i>Coniferae</i> (or <i>pinaceae</i> )	<i>Abies pectinata</i> , DC.	European silver fir	British Isles†	Air-dry		
247		<i>Abies pindrow</i> , Spach.	W. Himalayan silver fir, Paludár, Bádár	India	Air-dry		0.385
248		<i>Agathis alba</i>	Damar Minyak	Fed. Malay States	Air-dry		0.497
249		<i>Agathis australis</i> , Steud.	Kauri pine	New Zealand	Air-dry		0.438
250		<i>Agathis robusta</i> , F. M. Bailey	Queensland kauri, Dundathu pine	Queensland			0.433†
251		<i>Araucaria bidwillii</i> , Hook.	Bunya pine	Queensland	Air-dry		0.468
252		<i>Araucaria cunninghamii</i> , Sweet.	Moreton Bay pine, hoop pine	New South Wales, S. Queensland	Air-dry		0.470
253		<i>Athrotaxis selaginoides</i> , D. Don.	King William pine	Tasmania			0.369†
254		<i>Callitris arborea</i> , Schrad.	Clanwilliam cedar	S. Africa			0.618†
255		<i>Callitris calcarata</i> , R. Br.	Black cypress pine	New South Wales, Queensland			0.753†
256		<i>Callitris rhomboidea</i> , R. Br.	Illawara Mountain pine, cypress pine	India†	Green	0.516	
257		<i>Callitris robusta</i> , R. Br.	White cypress	W. Australia			0.657†
258		<i>Callitris tasmanica</i> , R. T. B.	Oyster Bay pine	Victoria, N. S. W., Tasmania			0.673†
259		<i>Cedrus deodara</i> , Loud.	Deodar, Himalayan cedar	India	Green	0.468	
					Air-dry		
					Oven-dry		
260		<i>Cryptomeria japonica</i> , D. Don.	Japanese cedar	India†	Green	0.329	
261		<i>Cupressus macrocarpa</i> , Hartw.	Monterey cypress	India†	Green	0.433	
262		<i>Cupressus torulosa</i> , D. Don.	Himalayan cypress	India	Green	0.419	
					Air-dry		0.431
263		<i>Dacrydium colensoi</i> , Hook.	Westland pine, silver pine	New Zealand	Air-dry		0.547
264		<i>Dacrydium cupressinum</i> , Soland.	Rimu, red pine	New Zealand	Air-dry		0.451
265		<i>Dacrydium franklinii</i> , Hook.	Huon pine	Tasmania	Air-dry		0.536†
266		<i>Juniperus procera</i> , Hochst.	East African juniper	E. Africa	Air-dry		0.548
267		<i>Larix europaea</i> , DC.	Larch	British Isles†			
268		<i>Libocedrus doniana</i> , Endl.	Kawaka, Wawaku	New Zealand			0.637†
269		<i>Phyllocladus rhomboidalis</i> , A. Rich.	Celery-top pine	Tasmania			0.609†
270		<i>Picea excelsa</i> , Link.	Norway spruce	British Isles†	Air-dry		
271		<i>Picea morinda</i> , Link.	W. Himalayan spruce, Rai	India			
					white wood	Air-dry	0.402
					red wood	Air-dry	0.436
272		<i>Pinus excelsa</i> , Wall.	Bhotan pine, blue pine, Kail, Piuni	India	Air-dry		0.405
273		<i>Pinus longifolia</i> , Roxb.	Long-needed pine, Chir	India	Green	0.541	
					Air-dry		0.505
274		<i>Pinus pinaster</i> , Soland.	Cluster pine, maritime pine	British Isles†	Air-dry		
275		<i>Pinus pinea</i> , Linn.	Stone pine	S. Africa†			0.565†
276		<i>Pinus strobus</i> , Linn.	Weymouth pine, white pine	British Isles†	Air-dry		
277		<i>Pinus sylvestris</i> , Linn.	Dantzic fir, Scots pine	British Isles			
					heavy timber	Air-dry	
					light timber	Air-dry	
278		<i>Podocarpus dacrydioides</i> , A. Rich.	Kahikatea, white pine	New Zealand			0.436†
279		<i>Podocarpus elata</i> , R. Br.	Brown pine	New South Wales, S. Queensland			0.817†
280		<i>Podocarpus elongata</i> , L'Her	Outeniqua or bastard yellowwood, Geelhout, um-Koba	S. Africa		0.450	0.481
281		<i>Podocarpus ferrugineus</i> , Don.	Miro, black pine	New Zealand			0.658†
282		<i>Podocarpus gracilior</i> , Pilg.	Musengera, Podo	E. Africa	Air-dry		0.513
283		<i>Podocarpus milanjanus</i> , Rendle	Podo	E. Africa	Air-dry		0.574
284		<i>Podocarpus neriifolia</i> , Don.	Welimadá, Thitmin	India			0.673†
285		<i>Podocarpus spicata</i> , R. Br.	Matai, black pine	New Zealand	Air-dry		0.715
286		<i>Podocarpus thunbergii</i> , Hook. var. <i>falcata</i> , Sim.	Upright or real yellow wood, um-Sunti	S. Africa		0.597	0.626
287		<i>Podocarpus totara</i> , Don.	Totara	New Zealand	Green	0.407	
288		<i>Pseudotsuga douglasii</i> , Carr.	Douglas fir	British Isles†	Air-dry		
289		<i>Sequoia sempervirens</i> , Endl.	Redwood	Australia†			0.465†
290	<i>Cornaceae</i>	<i>Curtisia faginea</i> , Ait.	Assagai, um-Gxina	S. Africa			0.940†
291	<i>Cunoniaceae</i>	<i>Ackama muelleri</i> , Benth.	Corkwood	Australia			0.641†
292		<i>Ceratopetalum apetalum</i> , D. Don.	Coachwood	Australia			0.608†
						0.657	
293		<i>Cunonia capensis</i> , Linn.	Red alder, Rode Els, um-Nqwaskube	S. Africa			0.721
						0.527	
294		<i>Platylophus trifolius</i> , Don.	White alder, Witte Els	S. Africa			0.575

\* Tension parallel to grain. † Not a native of this country.

† Bulk density calculated from weight and volume at time of test, no determination of moisture content having been made.



9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
0.772	10	4.43	5.60	894	0.120	0.222					3.08	3.93	852	0.772	0.816	1.073						(15)	
	54	4.85	7.94	1168	0.114		12.46	1615	0.552	99	2.74	3.93	1395	0.823	0.752	0.974	0.369	0.443	658	699	667	(9, 31, 38)	
	13	6.50	10.81	1340	0.179		18.11	2442	0.745	122	3.42	5.82	1575	1.21	1.13	1.195	0.608	0.632	1000	930	974		
	9	8.51	12.92	1538	0.264		16.70	2230	0.707	127	3.60	6.77	1715	1.32	1.146	1.20	0.780	0.871	1162	960	946		
0.840	70	5.04	11.10	1292	0.108							8.29										(8, 12)	
	10																						
0.37-0.52	28		4.22									4.99			0.415							(22)	
	13		4.78									6.82			0.661						(23)		
		3.66	6.22	1224								4.24										(5)	
0.45-0.75	16	3.86	6.02	1070	0.079		7.77	1280	0.266	48	2.82	3.30	1682	0.323	0.537	0.496	0.179	0.169	284	184	204	(38)	
	18	4.64	8.12	1343																		(21)	
	15	4.85	6.60	937	0.159							4.29					12.73*					(1, 3, 4, 19, 28, 51)	
			4.96	652																		(61)	
	12		9.79									5.50										(6)	
	15		6.32	1440								5.27	914		1.05		10.15*					(6, 9, 58, 59)	
			3.95	581																		(61)	
		3.32	5.81	617	0.099							3.87				0.356						(55, 56)	
			2.85	844																		(61)	
	31	3.39	4.60	648	0.103		7.27	851	0.358	58	1.89	2.75	99	0.703	0.721	0.671	0.126	0.369	481	386	377	(38)	
			6.32	749																		(61)	
			6.07	1252																		(61)	
0.30-0.52	45	3.62	6.09	948	0.079		8.51	1009	0.398	51	2.13	3.12	993	0.467	0.569	0.714	0.165	0.249	329	252	265	(31, 38)	
		4.61	7.41	1022	0.171						3.05	4.31	1067	0.618	0.749	0.861	0.249	0.225	447	304	340		
		7.17	9.25	1191	0.238						4.58	6.28	1440	0.917	0.632	0.544	0.179	0.246	540	390	406		
	24	2.12	4.01	495	0.052		5.26	618	0.251	36	0.77	1.60	457	0.306	0.531	0.517	0.186	0.260	163	170	147	(38)	
	40	2.52	4.35	647	0.057		7.28	886	0.348	43	1.17	2.27	668	0.429	0.534	0.696	0.151	0.295	340	265	288	(38)	
	35	2.57	4.13	579	0.065		6.29	811	0.276	53	1.89	2.22	784	0.467	0.548	0.668	0.137	0.341	334	231	227	(38)	
	10	4.70	6.43	746	0.170		9.34	1193	0.413	56	2.09	3.34	785	0.685	0.731	0.872	0.211	0.559	438	263	293	(38)	
	17	3.82	6.85	1006								5.48					12.87*					(4, 28)	
	14	4.86	7.85	1273								4.33					10.07*					(1, 3, 4, 19, 28)	
		3.14	6.96	467	0.111																	(3)	
	15		3.38									4.85				0.309						(22)	
	0.45-0.75		4.80	11.25	1700							6.43											(5)
		3.80	6.07	664	0.141																	(3)	
			7.33	1177																		(61)	
		4.42	7.42	1371								4.70										(5, 61)	
0.41-0.59	15	3.81	6.17	1020	0.081		8.26	1331	0.285	53	2.14	3.15	1447	0.469	0.684	0.710	0.274	0.249	326	202	220	(38, 39)	
	14	4.32	7.21	1114	0.096		9.01	1550	0.297	66	2.21	3.24	1512	0.477	0.885	0.805	0.278	0.310	336	252	268	(38, 39)	
	14	3.23	4.77	693								4.40			0.802							(31, 38)	
	78	3.25	5.53	1047	0.057		8.13	1205	0.309	61	2.13	2.86	1136	0.531	0.601	0.618	0.222	0.228	261	252	318	(31, 38)	
	15	4.02	6.90	1175	0.077		9.32	1662	0.301	61	2.18	3.57	1575	0.485	0.752	0.773	0.214	0.172	377	295	322	(31, 38)	
0.42 -0.55		2.81	7.17	971								4.94			0.771							(5, 55, 56)	
		2.70	7.35	669	0.061							3.49			0.579							(55, 56)	
		4.71	10.23	1202								6.25										(5)	
0.51 -0.76 0.375-0.50		5.22	10.97	1821								7.10					5.62*					(5, 26)	
		3.68	8.30	1329								5.23										(5, 25)	
		2.19	5.42	889								3.19					9.46*					(3, 4, 19, 28)	
0.500		5.83	896																			(61)	
	110	4.08	6.08	837	0.113							3.76			0.427							(8, 12, 55)	
	10																						
		5.22	9.62	759	0.202																(3)		
	13		6.12									4.08			0.372							(22)	
	15		5.91									4.01			0.507							(22)	
			9.29	1110								5.62			1.097							(10, 43)	
	12	6.73	9.98	1119	0.235							3.52					>4.92*					(3, 4, 13, 28)	
	100	4.76	7.13	854	0.149							4.24			0.413							(8, 12, 55)	
	10																						
	0.650	45	3.12	5.09	831								3.03			0.703		10.20*					(1, 3, 4, 19, 28)
	0.45-0.55		4.38	7.47	1300								5.17										(5)
			6.52	1120																		(61)	
		7.47	11.07	1486	0.212							6.04			0.939							(12, 55)	
			10.34	1550																		(61)	
			7.42	1109								4.66	941		1.365		9.03*					(59)	
0.750	60	5.35	8.50	1238	0.129							4.71			0.771							(8, 55)	
	10																						
	0																						
0.605	130	3.50	4.91	527	0.130							4.20			0.458							(8, 55)	
	10																						
0																							

1	2	3	4	5	6	7	8
295		<i>Weinmannia lachnocarpa</i> , F. Muell.	Mararie	New South Wales, Queensland			0.802†
296		<i>Weinmannia racemosa</i> , Linn., f.	Kamahi	New Zealand	Green	0.512	
296.5	<i>Dilleniaceae</i>	<i>Dillenia indica</i> , Linn.	Ottengah, Thabyu, Chalta	India			0.705†
297	<i>Dipterocarpaceae</i>	<i>Anisoptera</i> sp.	Sanai	Fed. Malay States	Air-dry		0.489
298		<i>Balanocarpus maximus</i> , King.	Chengal, Penak	Fed. Malay States	Air-dry		0.785
299		<i>Balanocarpus penangianus</i> , King.	Damar Hitan	Fed. Malay States	Green	0.589	
300		<i>Balanocarpus</i> sp.	Chengal, Penak	Fed. Malay States	Air-dry		0.609
301		<i>Dipterocarpus alatus</i> , Roxb.	Kanyin	India	Green	0.574	
					Air-dry		0.604
					Oven-dry		
302		<i>Dipterocarpus pilosus</i> , Roxb.	Hollong	India			0.689†
303		<i>Dipterocarpus</i> sp.	Keruing, Kruin	Fed. Malay States, Borneo	Air-dry		0.665
304		<i>Dipterocarpus tuberculatus</i> , Roxb.	In, Soohahn	India	Green	0.726	
					Air-dry		
305		<i>Dipterocarpus turbinatus</i> , Gaertn. F.	Gurjan	India	Green	0.655	
					Air-dry		
					Oven-dry		
306		<i>Dryobalanops aromatica</i> , Gaertn.	Kapur	Fed. Malay States	Air-dry		0.689
			Camphor-wood	Borneo			
307		<i>Dryobalanops</i> sp.	Keladan	Fed. Malay States	Green	0.601	
308		<i>Hopea odorata</i> , Roxb.	Thingan, Rinda	India			0.785†
309		<i>Hopea</i> sp.	Merawan	Fed. Malay States	Green	0.608	
310		<i>Shorea acuminata</i> , Dyer	Meranti Rambai Daun	Fed. Malay States	Green	0.447	
311		<i>Shorea assamica</i> , Dyer	Makai	India			0.577†
312		<i>Shorea barbata</i> , Brandis	Rasak	Fed. Malay States	Air-dry		0.817
313		<i>Shorea contorta</i> , Vidal	White Lauan	Australia			0.513†
314		<i>Shorea curtisii</i> , Dyer	Seriah	Fed. Malay States	Air-dry		0.513
315		<i>Shorea</i> , <i>Hopea</i> and <i>Isoptera</i> spp.	Salangan batu, Yacal	Borneo	Green	0.689	
316		<i>Shorea leprosula</i> , Miq.	Meranti Bunga	Fed. Malay States	Air-dry		0.483
317		<i>Shorea macroptera</i> , Dyer	Melantai	Fed. Malay States	Green	0.454	
318		<i>Shorea obtusa</i> , Wall.	Thitya	India			0.961†
319		<i>Shorea parvifolia</i> , Dyer	Meranti Sarang Punai	Fed. Malay States	Air-dry		0.436
320		<i>Shorea robusta</i> , Gaertn., f.	Sál, Sákher	India	Green	0.714	
					Green	0.772	
321		<i>Shorea sericea</i> , Dyer	Meranti Kepong	Fed. Malay States	Air-dry		0.374
322		<i>Shorea</i> sp.	Damar Laut Daun Besar	Fed. Malay States	Air-dry		0.837
			Damar Laut Daun Kechil	Fed. Malay States	Air-dry		0.920
			Merani Kait Kait	Fed. Malay States	Green	0.513	
			Seraya Batu	Fed. Malay States	Air-dry		0.777
			White Seriah, cedar	Borneo			0.481-0.641†
323		<i>Vatica affinis</i> , Thw.	Mandora	Ceylon			0.957†
324	<i>Ebenaceae</i>	<i>Diospyros kurzii</i> , Hiern.	Andaman marble-wood, Thitkya,	India			0.978†
			Pecha-da				
325		<i>Diospyros melanida</i> , Poir.	Ebène marbre	Mauritius			0.768†
326		<i>Diospyros pentamera</i> , Woods and F. Muell.	Grey plum	New South Wales, Queensland			0.705†
327		<i>Diospyros</i> sp.	Kayu Arang	Fed. Malay States	Air-dry		0.798
328		<i>Euclea natalensis</i> , A. DC.	i-Dungamuzi	S. Africa			0.890†
329		<i>Royena lucida</i> , Linn.	Black-bark, Zwartbast, um-Tenattena	S. Africa			0.770†
330	<i>Elaeocarpaceae</i>	<i>Aristotelia racemosa</i> , Hook., f.	Moko	New Zealand			0.593†
331		<i>Elaeocarpus dentatus</i> , Vahl.	Hinau	New Zealand			0.562†
332		<i>Elaeocarpus grandis</i> , F. Muell.	Blue fig	Australia			0.665†
333		<i>Sloanea woollsii</i> , F. Muell.	Mellow Carrabeen	Australia			0.577†
334	<i>Eucryphiaceae</i>	<i>Eucryphia billiardieri</i> , Spach.	Leatherwood	Tasmania			0.785†
335	<i>Euphorbiaceae</i>	<i>Baccaurea sapida</i> , Muell. Arg.	Latecku, Lutio, Kanazo	India			0.673†
336		<i>Beyeria viscosa</i> , Miq.	Pinkwood	Australia			0.704†
337		<i>Bischofia javanica</i> , Bl.	Uriana, Tayôkthé, Aukkyu, Bo-ungza, red cedar	India			0.721†
338		<i>Bridelia micrantha</i> , Baill.	um-Hlahlamakwaba, Mazerie	S. Africa			0.590†
339		<i>Hemicyclia australasica</i> , Muell. Arg.	Yellow tulip wood	Queensland, N e w South Wales			0.865†
340		<i>Ricinodendron africanus</i> , Muell. Arg.	Ochwen	W. Africa			0.789†
341	<i>Fagaceae</i>	<i>Castanea sativa</i> , Mill.	Sweet chestnut	British Isles†	Air-dry		
342		<i>Castanopsis hystrix</i> , A. DC.	Chestnut, Dalné, Hingori, Sirikishu	India			0.737†
343		<i>Castanopsis</i> sp.	Berangan	Fed. Malay States	Green	0.569	
344		<i>Fagus cunninghamii</i> , Hook.	Tasmanian myrtle, red myrtle	Australia	Green	0.656	
345		<i>Fagus fusca</i> , Hook., f.	Red beech, black birch, Towai	New Zealand			0.577†
346		<i>Fagus menziesii</i> , Hook., f.	Silver beech, red birch, Towai	New Zealand			0.593†
347		<i>Fagus moorei</i> , F. Muell.	Negro head, white beech	New South Wales			0.860†
348		<i>Fagus sylvatica</i> , Linn.	Beech	British Isles	Air-dry		
349		<i>Quercus lamellosa</i> , Sm.	Hill oak, Búk.	India			0.945†
350		<i>Quercus pedunculata</i> , Ebrh.	Oak	British Isles	Air-dry		0.744
351		<i>Quercus robur</i> , Linn.	Oak	British Isles	Air-dry		
352		<i>Quercus sessiliflora</i> , Salisb.	Oak	British Isles			0.785†

\* Tension parallel to grain. † Not a native of this country.

‡ Bulk density calculated from weight and volume at time of test, no determination of moisture content having been made.



9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
			13.30	1892																		(61)
	71	2.68	5.38	845	0.056	0.725					2.04	2.39		0.524	0.860	0.956	0.363	0.497	406	336	365	(29)
			8.34	1036								5.17				1.014						(10, 43)
	19	3.44	6.46	1012																		(21)
	17	7.81	11.49	1723																		(21)
	24	4.28	7.76	1192																		(21)
	17	6.75	9.93	1455																		(21)
	73	3.76	6.61	1039	0.077		10.70	1482	0.443	74	1.71	3.18	1122	0.534	0.671	0.752	0.506	0.745	402	413	392	(31, 38)
	17	4.25	8.79	1333	0.077		13.04	1553	0.629	76	2.86	4.57	1207	0.618	0.885	1.044	0.432	0.594	503	447	438	
		7.81	9.61	1346	0.252						4.22	6.62	1501	0.784	0.889	0.904	0.639	0.714	680	537	501	
		11.49																				(34, 43)
	17	4.29	7.41	1237												0.787						(9, 21)
	50	4.91	8.15	1233	0.110		14.13	1886	0.604	102	2.58	3.96	1422	0.858	0.840	0.946	0.415	0.671	660	644	644	(31, 38, 46)
		5.07	9.79	1381	0.105						2.49	4.77	1523	0.633	0.970	1.125	0.566	0.756	715	733	710	
	66	4.88	7.75	1420	0.095		13.12	1896	0.507	81	2.73	4.12	1597	0.668	0.622	0.742	0.520	0.622	481	463	458	(38)
		5.69	10.97	1574	0.117						2.62	5.44	1672	0.833	0.816	0.946	0.886	0.618	596	633	583	
		9.47	13.83	1775	0.288						6.68	8.75	1624	0.956	0.932	0.886	0.625	0.724	703	664	646	
	19	5.03	10.04	1680								3.89										(9, 21)
	21	3.94	8.64	1399																		(21)
			11.50	1465								5.87			1.46							(10, 30, 31, 43)
	20	5.68	10.28	1623																		(21)
	20	3.38	6.62	1005																		(21)
			8.30	1102								4.49			0.934							(10, 43)
	18	5.92	13.73	2005																		(21)
			6.25	663																		(61)
	19	3.84	7.58	1234																		(21)
	28		8.66	1425								5.22										(9, 37)
	18	3.83	6.85	1203																		(21)
	21	3.97	6.77	1244																		(21)
			15.64	1776								8.54			1.873							(9, 31, 43)
	19	3.30	5.83	1033																		(21)
	56	5.56	9.92	1373	0.128		13.44	1792	0.569	101	3.53	4.65	1432	0.984	0.914	0.972	0.480	0.678	625	679	692	(31, 36, 38, 40, 43)
	28	5.55	10.65	1350	0.136							5.76			1.307							(21)
	17	2.85	5.28	1005																		(9, 21)
	17	6.02	13.32	1920																		
	17	6.33	12.88	1860																		
	31	4.10	7.53	1417																		
	16	5.17	9.21	1167																		
			7.20									3.59										
		5.46	9.64	1316	0.107							4.12			0.436							(54)
			7.80	1270								6.30			1.49							(10, 43)
		3.78	5.55	1007								4.43			1.068							(63)
			9.75	1502																		(61)
	16	5.38	11.02	1596																		(21)
		4.69	8.98	1488	0.081							4.84										(12)
		2.86	6.57	668	0.068							4.24										(12)
		3.14	6.17	452	0.131																	(3)
		4.76	6.33	975	0.129																	(3)
			8.11	1184								5.58	1087		1.466		12.46*					(59)
			9.08	1342																		(61)
			14.10	1668																		(2)
			7.51	925								4.62			0.786							(10)
		5.06	9.86	867	0.164																	(3)
			6.02	598								4.42										(10, 43)
		3.16	5.25	976	0.060							5.05										(12)
			8.82	1237																		(2, 61)
		3.81	6.29	1046								3.78			0.687							(57)
0.44-0.60		2.90	7.70	925								5.17										(5)
			7.42	908								4.05			1.274							(10, 43)
	22	3.87	6.94	1073																		(21)
	28	4.98	6.40	1327	0.104							4.07			0.876		6.27*					(51, 61)
			8.08	1054								4.20			0.63		5.60*					(3, 13, 28)
			7.73	914								4.20			0.63		5.60*					(3, 13, 28)
			8.15	1157								5.22	1274		0.736		14.40*					(2, 13, 59)
0.61-0.75		3.69	10.34	1389								5.09					7.73*					(1, 5)
			8.94	1225								5.18			1.69							(10, 31, 43)
	12		8.30									6.05					7.38*					(20)
0.60-0.813		3.78	10.37	1533								6.22					7.03-13.35*					(1, 5, 25)
			6.85	805																		(12)

1	2	3	4	5	6	7	8
354	Flacourtiaceae	<i>Dorvalis zizyphoides</i> , E. Mey.	Zuurbesjes, um-Kokolo	S. Africa			0.870†
355		<i>Kiggelaria africana</i> , Linn.	Wild peach, Spekhout, Mpataselo	S. Africa			0.650†
356		<i>Scolopia ecklonii</i> , Arn.	Red pear, Rode Peer	S. Africa			0.840†
357		<i>Scolopia zeyheri</i> , Arn.	Thorn pear, Wolvedoorn	S. Africa			1.000†
358		<i>Trimeria alnifolia</i> , Harv.	Wild mulberry, Wilde Moerbe, Xal-ebo	S. Africa			0.790†
359	Guttiferae	<i>Calophyllum bracteatum</i> , Thw.	Walukina	Ceylon			0.519†
360		<i>Calophyllum calaba</i> , Linn.	Gurukina	Ceylon			0.705†
361		<i>Calophyllum inophyllum</i> , Linn.	Alexandrian laurel, Tharapi, Sultana champa, Puna	India			0.673†
362		<i>Calophyllum</i> sp.	Bintangor	Fed. Malay States	Air-dry		0.529
363		<i>Calophyllum spectabile</i> , Willd.	Dakar talada, Pantaga, Lal chuni	India			0.617†
364	Lauraceae	<i>Garcinia conrauana</i> , Engl.	Orugbo	W. Africa			0.716†
365		<i>Kayea assamica</i> , King and Prain	Sia Nahor	India	Green	0.745	
366		<i>Mesua ferrea</i> , Linn.	Penaga (F. M. S.), Nageshwa, Gangaw	India	Air-dry		0.897
367	Hamamelidaceae	<i>Bucklandia populnea</i> , R. Br.	Pipli, Dinghab, Singliang	India			0.721†
368		<i>Parrotia jacquemontiana</i> , Dene.	Peshora, Shtar	India	Green	0.694	
369	Icacinaceae	<i>Apodytes dimidiata</i> , E. Mey.	White pear, Witte Peer, um-Dakane	S. Africa		0.636	0.670
370	Lauraceae	<i>Villaresia moorei</i> , F. Muell.	New South Wales maple	Australia			0.689†
371		<i>Beilschmiedia obtusifolia</i> , Benth.	Pomatum wood, She beech	New South Wales, Queensland			0.737†
372		<i>Beilschmiedia tarairi</i> , Benth. and H., f.	Taraire	New Zealand			0.888†
373		<i>Beilschmiedia tawa</i> , Benth. and H., f.	Tawa	New Zealand	Green	0.533	
					Air-dry		0.555
374		<i>Cinnamomum oliveri</i> , F. M. Bailey	Black sassafras	Australia			0.513†
375		<i>Cryptocarya patentinervis</i> , F. Muell.		New South Wales, Queensland			0.657†
376		<i>Endiandra discolor</i> , Benth.	Murrogun	New South Wales, Queensland			0.753†
377		<i>Endiandra pubens</i> , Meissn.		Queensland			0.721†
378		<i>Eusideroxylon zwageri</i> , Teijsm. and Binn.	Borneo ironwood, Billian	Borneo	Green	0.960	
379		<i>Litsea calicaris</i> , Kirk.	Billian	Fed. Malay States	Air-dry		0.938
380		<i>Litsea reticulata</i> , Meissn.	Mangi, Mangeao, Tangeao	New Zealand			0.621†
381		<i>Litsea reticulata</i> , Meissn. and <i>Litsea ferruginea</i> , Bl.	She beech, Bally Gum	Australia			0.433†
382		<i>Litsea</i> sp.	Bally gum	Australia	Air-dry		0.484
383		<i>Litsea</i> ? sp.	Medang	Fed. Malay States	Green	0.601	
384		<i>Machilus odoratissima</i> , Ness.	Medang Tandok	Fed. Malay States	Air-dry		0.721
			Lalic, Leddil, Kaula, Seiknangyi	India			0.641†
385		<i>Ocotea bullata</i> , E. Mey.	Black stinkwood, stinkhout	S. Africa		0.659	0.758
386		<i>Ocotea usambarensis</i>	Muzaiti, camphor	E. Africa	Green	0.547	
387		<i>Persea semicarpifolia</i>	Ranai	Ceylon	Air-dry		0.558
388	Leguminosae	<i>Acacia acuminata</i> , Benth.	Jam wood	W. Australia	Green	0.935	1.015†
389		<i>Acacia arabica</i> , Willd.	Babul, Kikar	India			0.865†
390		<i>Acacia horrida</i> , Willd.	Doornboom, thorn tree, um-Nga	S. Africa			0.790†
391		<i>Acacia melanoxylon</i> , R. Br.	Blackwood	E. Australia, Tasmania			0.675†
392		<i>Acacia natalitia</i> , E. Mey.	u-Munga	S. Africa			0.700†
393		<i>Adenanthera pavonina</i> , Linn.	Recheda, Yivè, redwood	India			0.898†
394		<i>Afrormosia laxiflora</i> , Harms.	Ainyesan	W. Africa			0.802†
395		<i>Azelia africana</i> , Sm.	Aligna	W. Africa	Oven-dry		
396		<i>Azelia</i> spp.	Merabau	Fed. Malay States			
			Ipil	Borneo	Green	0.718	
397		<i>Albizzia fastigiata</i> , Oliver	Flat crown, Nebelele, um-Hlandhloti	S. Africa		0.415	0.444
398		<i>Albizzia lebbek</i> , Benth.	Sirio, Siris, Kôkko, walnut	India			0.753†
399		<i>Albizzia odoratissima</i> , Benth.	Suriya Mara, Thitmagyi	Ceylon			0.914†
400		<i>Albizzia procera</i> , Benth.	Thitpyu, Sit, White Siris	India			0.737†
401		<i>Bauhinia variegata</i> , Linn.	Kachnar, Bwèchin, Bwegyin	India			0.705†
402		<i>Berlinia acuminata</i> , Soland.	Ekpagoy	W. Africa			0.891†
403		<i>Brachystegia spicaeformis</i> , Benth.	Okwein	W. Africa	Air-dry		0.645
404		<i>Cassia siamea</i> , Lam.	Johor	Fed. Malay States	Air-dry		0.849
405		<i>Castanospermum australe</i> , A. Cunn.	Black bean	New South Wales, Queensland			0.837†
406		<i>Cylicodiscus gabunensis</i> , Harms.	African greenheart, Okan	W. Africa			0.934†
407		<i>Dalbergia latifolia</i> , Roxb.	East Indian rosewood, blackwood, Kala Shishâm	India			0.882†
408		<i>Dalbergia sissoo</i> , Roxb.	Sissoo, Shishâm	India			0.770†
409		<i>Detarium senegalense</i> , J. F. Gmel.	Ogwega	W. Africa			1.091†

\* Tension parallel to grain.

† Bulk density calculated from weight and volume at time of test, no determination of moisture content having been made.



9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0.690		2.93	5.37	618	0.086							3.65										(12)
		2.93	5.55	712	0.074							4.10										(12)
		3.52	7.00	849	0.084							3.98										(12)
		3.52	8.95	906	0.076							5.03										(12)
		3.52	8.35	909	0.076							5.08										(12)
		3.54	6.34	1157	0.060							4.32			0.237							(54)
		3.43	6.14	1037	0.059							3.79			0.666							(54)
			6.57	745								4.61			1.232							(10, 43)
	18	4.83	8.98	1490								4.28			1.030							(21)
			7.21	855								5.20			>0.317		7.02*					(.0, 43)
		< 19.67		1307								4.77	1520	1.026	1.061	1.100	0.496	0.513	801	760	785	(11)
	41	5.01	8.90	1318	0.106		15.10	2135	0.599	107	2.66	9.99			1.883							(38)
	16	8.44	16.07	2025								4.00			0.905							(10, 21, 31, 43)
			7.20	973								5.57			0.996							(10, 43)
	33	2.72	6.62	752	0.051																	(40)
	50																					
	10	4.23	9.36	1119	0.092																	(8, 12, 55)
	0																					
			11.98	1670																		(61)
			5.34	910																		(61)
		5.04	5.69	996	0.137																	(3)
	63	3.94	6.16	1155	0.076	0.654					2.22	3.04		0.604	0.699	0.860						(3, 4, 29)
	15	4.36	7.71	1140	0.094	0.499					2.90	3.69		0.821	1.010	1.104	0.300	0.739	526	386	376	(3, 4, 29)
																	10.13*					
			7.53	1113																		(61)
			9.29	1363																		(61)
			11.39	1372																		(2, 61)
			9.03	1303																		(61)
	23		13.81	1676								7.94										(9, 37)
	14	9.39	17.33	2398																		(21)
		5.52	6.97	901	0.188																	(3)
			5.77	925																		(61)
	17		6.93-									3.66-4.29										(6)
			7.84																			
	20	3.30	6.46	1406																		(21)
	16	5.62	11.02	1623																		(21)
			5.89	886																		(10, 43)
0.800	80											3.41			0.907							
	10	8.06	11.49	1254	0.292							6.44			0.918							(8, 12, 55)
	0																					
	83		2.46									3.38			0.429							(22)
	13		5.56									4.71			0.485							(23)
		4.81	7.42	722	0.174							4.10			0.650							(54)
	25	9.98	10.75	1655											0.830		8.44*					(20)
			11.13	1262								<11.83										(31)
		2.42	5.78	698	0.048							4.27										(12)
			7.80	1138								5.45	1260		1.453		11.03*					(51, 58, 59)
0.639		2.34	5.99	593	0.053							3.71										(12)
			10.13	1314								7.13			1.499							(10, 43)
		3.79	7.14	1284								4.68			0.648							(57)
	9	7.41	12.66	1516	0.188	0.765					4.77	6.75	1550	1.208	1.326	1.589						(15)
	21	6.87	11.51	1628								6.35										(21, 37)
	70																					
	10	6.33	9.54	961	0.232							4.77			1.012							(8, 12, 50, 57)
	0																					
			9.29	1157								6.73			1.433							(10, 41, 48)
0.460		7.02	10.27	1220	0.224							6.58			0.902							(54)
			12.63	1456								7.45			1.733							(9)
			3.84	370								2.90			0.981							(10, 13)
		2.18	6.11	981								3.78			0.543							(57)
	10	6.82	12.13	1672	0.145	0.785					4.47	6.58	1673	1.062	1.136	0.973						(15)
	18	6.23	10.84	1392																		(21)
			8.87	1188								4.28	994		1.742		6.58*					(2, 50)
		5.44	8.98	1277								5.12			1.017							(57)
			13.64	1247								7.61										(9, 31)
			9.96	1146								7.49										(31, 13)
		6.43	11.36	1458								6.23			0.785							(57)

1	2	3	4	5	6	7	8
410		<i>Dialium platysepalum</i> , R. T. B.	Kranji	Fed. Malay States	Green	0.785	
411		<i>Erythrina caffra</i> , Thunb.	Kafirboom, um-Sinsi	S. Africa	Air-dry		0.240
412		<i>Hardwickia binata</i> , Roxb.	Anjan, Acha, Yepa	India			1.313†
413		<i>Koompassia parvifolia</i> , Prain	Tualang	Fed. Malay States	Air-dry		0.657
414		<i>Milletia caffra</i> , Meissn.	Kaffir ironwood, um-Zimbati	S. Africa			1.150†
415		<i>Pericopsis mooniana</i> , Thw.	Nedun, Hedun	Ceylon			1.135†
416		<i>Piptadenia africana</i> , Hook., f.	Ekhimi, Agboin, West African green-heart	W. Africa	Oven-dry		
417		<i>Pterocarpus indicus</i> , Willd.	Padauk	India	Air-dry		0.685
418		<i>Pterocarpus macrocarpus</i> , Kurz.	Burma Padauk	India			0.865†
419		<i>Pterocarpus marsupium</i> , Roxb.	Bijasâl, Vengai	India			0.881†
420		<i>Pterocarpus santalinus</i> , Linn., f.	Red Sanders, Lal Chandanum	India			1.202†
421		<i>Pterolobium</i> sp.	Agba	W. Africa	Air-dry		0.463
422		<i>Sindora</i> sp.	Sepetir	Fed. Malay States	Air-dry		0.508
423		<i>Sophora tetraptera</i> , J. Mill., var. <i>grandiflora</i> , Hook., f.	Kohwai	New Zealand			0.884†
424		<i>Virgilia capensis</i> , Lam.	Keur, vetch-leaved Virgilia	S. Africa			0.708†
425		<i>Xylia dolabriformis</i> , Benth.	Ironwood of Burma and Arracan, Pyinkado, Jambu	India			0.961†
426	Linaceae	<i>Ixonanthes icosandra</i> , Jack.	Pagar Anak	Fed. Malay States	Air-dry		0.697
427	Loganiaceae	<i>Buddleia salviifolia</i> , Lam.	Saliehout, Gwangi, sagewood	S. Africa			0.810†
428		<i>Nuxia floribunda</i> , Benth.	Wild elder, Vlier, um-Quaqu	S. Africa			0.706†
429		<i>Strychnos atherstonei</i> , Harv.	Cape Teak, Kajatenhout, um-Hamala	S. Africa			0.780†
430	Lythraceae	<i>Lagerstroemia flos-reginae</i> , Retz.	Pyinma, Ajhar, Jarul, Taman	India	Air-dry		0.566
431		<i>Lagerstroemia hypoleuca</i> , Kurz.	Pyinma, Pabda	India			0.641†
432		<i>Lagerstroemia lanceolata</i> , Wall.	Nana, Benteak	India			0.850†
433		<i>Lagerstroemia parviflora</i> , Roxb.	Indian Prima Vera, Dhauri, Lendia, Sida	India			0.849†
434		<i>Lagerstroemia</i> sp.	Bungor	Fed. Malay States	Air-dry		0.513
435		<i>Lagerstroemia tomentosa</i> , Presl.	Burmese Leza wood	India			0.802†
436	Magnoliaceae	<i>Michelia champaca</i> , Linn.	Sapu, Champaca, saga	Ceylon			0.638†
437		<i>Michelia excelsa</i> , Bl.	Magnolia, Bara champ, Gok	India			0.529†
438	Malvaceae	<i>Hibiscus tiliaceus</i> , Linn.	um-Lolwa	S. Africa			0.760†
439		<i>Thespesia populnea</i> , Soland.	Tulip tree, Portia tree, Suriya	India			0.806†
440	Meliaceae	<i>Cedrela toona</i> , Roxb.	Red cedar, Toon, Tun, Poma, Thitkado	Australia and India	Air-dry		0.479
441		<i>Chickrassia tabularis</i> , A. Juss.	Chikrassi, Arrodah, Yinma, Chittapong wood	India			0.785†
442		<i>Chloroxylon swietenia</i> , DC.	Satinwood, Buruta, Mutirai	Ceylon			1.031†
443		<i>Dysoxylon fraserianum</i> , Benth.	Rosewood	Australia			0.726†
444		<i>Dysoxylon muelleri</i> , Benth.	Red bean	Australia			0.723†
445		<i>Dysoxylon spectabile</i> , Hook., f.	Kohe Kohe	New Zealand			0.678†
446		<i>Ekebergia capensis</i> , Sparrm.	Dog plum, Essehout, Cape ash	S. Africa		0.490	0.517
447		<i>Ekebergia meyeri</i> , Presl.	Essehout	S. Africa			0.540†
448		<i>Entandrophragma candollei</i> , Harms.	Ikpwapobo	W. Africa			0.674†
449		<i>Guarea</i> sp.	Scented mahogany, cedar, Obobo-Nufwa	W. Africa			0.814†
450		<i>Guarea thompsoni</i> , Spr. and Hutch.	Obobo-Nikwi, cedar	W. Africa			0.774†
451		<i>Khaya ivorensis</i> , A. Chev.	Mahogany, Ogwango	W. Africa			0.668†
452		<i>Khaya senegalensis</i> , A. Juss.	Dry-zone mahogany, Ogwango	W. Africa			0.513†
453		<i>Melia azedarach</i> , Linn.	Margosa, Nym tree, Persian lilac, bastard cedar, Thamaga	Ceylon			0.758†
454		<i>Melia dubia</i> , Cav.	Lucumidella, Ceylon mahogany or cedar, Malai	Ceylon			0.327†
455		<i>Pseudocedrela</i> sp.	Apopo	W. Africa			0.519†
456		<i>Pteroxylon utile</i> , Eekl. and Zeyh.	Sneezewood, Nieshout, Mweri, um-Tati	S. Africa		0.956	0.991
457	Monimiaceae	<i>Doryphora sassafras</i> , Endl.	Sassafras	Australia			0.593†
458	Moraceae	<i>Artocarpus chaplasha</i> , Roxb.	Kaita-da, Chaplash, Chram, Taungpeinnè	India			0.545†
459		<i>Artocarpus hirsuta</i> , Lamk.	Aini, Ayani	India	Green	0.516	
460		<i>Artocarpus integrifolia</i> , Linn., f.	Jak, Kanthal, Peinnè, Pilla	Ceylon	Air-dry		0.695†
461		<i>Artocarpus lakoocha</i> , Roxb.	Dahu, Myauklot, Wonta	India			0.641†
462		<i>Artocarpus nobilis</i> , Thw.	Del, Bedi-del	Ceylon			0.770†
463		<i>Artocarpus rigida</i> , Bl.	Perian	Fed. Malay States	Air-dry		0.304
464		<i>Artocarpus</i> sp.	Keladang	Fed. Malay States	Green	0.601	
465		<i>Chlorophora excelsa</i> , Benth. and Hook.	Iroko, Odum	W. Africa	Air-dry		0.545
466		<i>Ficus natalensis</i> , Hochst.	Wild fig, um-Tombi	S. Africa			0.410†
467		<i>Ficus</i> sp.	Pulut Pulut	Fed. Malay States	Air-dry		0.336
468		<i>Sloetia sideroxylon</i> , Teijsm. and Binn.	Tempinis	Fed. Malay States	Air-dry		0.872

\* Tension parallel to grain.

† Bulk density calculated from weight and volume at time of test, no determination of moisture content having been made.



[illegible]

1	2	3	4	5	6	7	8
469	<i>Myristicaceae</i>	<i>Myristica irya</i> , Gaertn.	Black Chuglam, Maloh	India		0.663	0.833†
470	<i>Myrsinaceae</i>	<i>Myrsine melanophlaeos</i> , R. Br.	Cape beech, Beukenhout, Magona	S. Africa			0.743
471		<i>Myrsine urvillei</i> , A. DC.	Mapau	New Zealand			0.991†
472	<i>Myrtaceae</i>	<i>Angophora intermedia</i> , DC.	Narrow-leaved apple	New South Wales, Queensland			0.929†
473		<i>Angophora lanceolata</i> , Cav.	Smooth-barked apple	New South Wales, Queensland			0.962†
474		<i>Angophora subvelutina</i> , F. Muell.	Rough-barked apple	New South Wales, Queensland			0.769†
475		<i>Backhousia myrtifolia</i> , Hook.	Grey myrtle	New South Wales, Queensland			1.042†
476		<i>Eucalyptus accedens</i> , Fitzg.	Powder bark	Australia			
477		<i>Eucalyptus acervula</i> , Hook., f.	Red gum	Tasmania			1.026†
478		<i>Eucalyptus acmenioides</i> , Schau.	White mahogany	New South Wales, Queensland	Green	0.757	
479		<i>Eucalyptus amygdalina</i> , Labill.	Black peppermint	Tasmania			0.930†
480		<i>Eucalyptus andrewsi</i> , J. H. M.	New England peppermint	New South Wales			0.849†
481		<i>Eucalyptus australiana</i> , R. T. B. and H. G. S.	Narrow-leaved peppermint	New South Wales, Victoria			0.792†
482		<i>Eucalyptus beyeri</i> , R. T. B.	Narrow-leaved ironbark	New South Wales			1.146†
483		<i>Eucalyptus bicolor</i> , A. Cunn.	Flooded box	New South Wales			1.021†
484		<i>Eucalyptus botryoides</i> , Sm.	Bangalay, mahogany	Queensland, Victoria			1.013†
485		<i>Eucalyptus bridgesiana</i> , R. T. B.	Apple, woolly-butt	New South Wales, Victoria			0.906†
486		<i>Eucalyptus calophylla</i> , R. Br.	Marri, red gum	W. Australia	Green	0.659	
487		<i>Eucalyptus campanulata</i> , R. T. B. and H. G. S.	Stringybark	Australia	Air-dry		0.801 0.833†
488		<i>Eucalyptus capitellata</i> , Sm.	Brown stringybark	Australia			0.994†
489		<i>Eucalyptus citriodora</i> , Hook., f.	Citron-scented gum	Queensland			0.930†
490		<i>Eucalyptus considaniana</i> , J. H. M.	White ash	New South Wales			0.930†
491		<i>Eucalyptus cornuta</i> , Labill.	Yate gum	W. Australia	Green	0.959	
492		<i>Eucalyptus corymbosa</i> , Sm.	Bloodwood	Australia	Air-dry		1.015 0.970†
493		<i>Eucalyptus corynocalyx</i> , F. Muell.	Sugar gum	S. Australia			1.115†
494		<i>Eucalyptus crebra</i> , F. Muell.	Narrow-leaved ironbark	Australia			1.120†
495		<i>Eucalyptus delegatensis</i> , R. T. B.	Southern Mountain ash, Tasman- ian oak	New South Wales, Victoria, Tasmania			0.657†
496		<i>Eucalyptus diversicolor</i> , F. Muell.	Karri	W. Australia	Green	0.749	
497		<i>Eucalyptus dives</i> , Schau.	Peppermint, messmate	Australia	Air-dry		0.829 1.157†
498		<i>Eucalyptus drepanophylla</i> , F. Muell.	Messmate, ironbark	Australia			1.077†
499		<i>Eucalyptus eugenioides</i> , Sieb.	White stringybark	E. Australia	Green	0.739	
500		<i>Eucalyptus fastigata</i> , H. D. and J. H. M.	Stringybark	New South Wales, Victoria			0.898†
501		<i>Eucalyptus fergusonii</i> , R. T. B.	Bloodwood ironbark	New South Wales			1.162†
502		<i>Eucalyptus fletcheri</i> , R. T. B.	River box	New South Wales, Victoria			1.066†
503		<i>Eucalyptus fraxinoides</i> , H. D. and J. H. M.	White ash	New South Wales			0.722†
504		<i>Eucalyptus globulus</i> , Labill.	Blue gum	India†	Green	0.676	
					Air-dry		0.806
				New South Wales, Victoria, Tasmania	Green	0.784	
					Air-dry		0.787
505		<i>Eucalyptus gomphocephala</i> , DC.	Tuart	S. W. Australia	Green	0.874	
506		<i>Eucalyptus gonicalyx</i> , F. Muell.	Mountain gum, grey gum		Air-dry		0.972 0.915†
507		<i>Eucalyptus hemilampra</i> , F. Muell.	Mahogany	New South Wales, Victoria, S. Australia			
508		<i>Eucalyptus hemiphloia</i> , F. Muell.	Grey box, white box, brush box, gum- top box	New South Wales Australia	Green	0.754	1.058†
					Air-dry		
509		<i>Eucalyptus intermedia</i> , R. T. B.	Bloodwood		Green	0.884	
510		<i>Eucalyptus jacksonii</i> , J. H. M.	Red Tingle Tingle, stringybark	New South Wales S. W. Australia			1.009†
					Green	1.170†	
					Air-dry		0.887 0.802†
511		<i>Eucalyptus laevopinea</i> , R. T. B.	Silvertop stringybark	Australia			1.245†
512		<i>Eucalyptus largiflorens</i> , F. Muell.	Red box	Australia			1.163†
513		<i>Eucalyptus leucosylon</i> , F. Muell.	Bluc gum	S. Australia			
514		<i>Eucalyptus longicornis</i> , F. Muell.	Morrell	W. Australia	Green	0.900	
					Air-dry		0.915
515		<i>Eucalyptus longifolia</i> , Lk. and Ott.	Woollybutt, peppermint	New South Wales, Victoria	Green	0.769	

\* Tension parallel to grain. † Not a native of this country.

‡ Bulk density calculated from weight and volume at time of test, no determination of moisture content having been made.



9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0.780	80		11.68	1341								6.52			1.318							(10, 43)
	10	4.32	7.07	1089	0.103							4.34			0.794							(8, 12, 55)
	0	4.66	9.75	825	0.154																	(3)
			11.74	1585																		(61)
			9.53	1339																		(61)
			6.91	1128																		(61)
			15.28	2120																		(61)
	44	8.47	10.20	1518																		(20)
			8.46	2132																		(2)
			10.21	1550	0.167							6.28	1713		0.971	1.041	7.39*					(2, 6, 24, 60)
			7.18	1960																		(2)
			6.83	1017																		(2)
			10.02	1446								6.41	1557		1.100		13.79*					(2, 59)
			12.22	1562																		(2)
			8.85	1114								4.01	982		1.160		11.54*					(2, 24, 59)
			10.93	1468								4.99	875		1.613		12.25*					(2, 59)
			6.12	945																		(2)
	75	6.32	7.98	1265								4.66	873		0.506		9.56*					(2, 20)
	12	8.86	11.67	1820								6.53	1389		0.808		14.20*					(2)
			9.38	1455																		(2)
			12.17	1588																		(2)
			8.69	1189																		(2, 24)
			12.48	1637																		(2)
	32	8.93	11.74	1617								4.69	999		0.879		13.85*					(2, 20)
	12	11.95	15.12	1969								8.16	1336		1.178		17.02*					(2, 6, 7, 24, 52, 59)
			9.81	1408								6.97	1354		1.373		13.88*					(59)
			7.24	1144								4.18	718		1.526		7.61*					(2, 24, 58, 59)
			12.25	1620								6.95	1536		1.540		12.97*					(2)
			9.55	1523																		(2)
	54	6.04	8.09	1230								3.87	926		0.633		9.25*					(2, 7, 20)
	12	9.53	12.16	1885								7.17	1425		0.738		13.18*					(27)
			11.30									4.84					11.04*					(24)
			9.67	1245																		(2, 59, 60)
	39		11.22	1460	0.172							5.70	1524		1.023	1.164	8.61*					(2)
			12.42	1987																		(2)
			15.94	2174																		(2)
			8.40	931																		(2)
			13.26	1782																		(2)
	52	4.60	7.93	1483	0.082		12.45	1703	0.508	104	2.27	3.59	2266	0.591	0.875	1.002	0.422	0.661	601	569	542	(38)
	13	8.00	12.79	2242	0.163		16.24	2604	0.602	135	3.79	5.83	2390	0.826	0.998	1.532	0.672	0.864	756	692	535	(2, 7, 20, 55, 56, 59)
	42	6.22	8.47	1652								3.99	1231		0.728		15.07*					(2, 7, 20)
	12	10.54	11.99	2355								6.24	1793		0.946		18.14*					(59)
	43	6.54	8.30	1146								4.91	1261		0.682		9.35*					(2, 7, 20)
	12	11.18	12.58	1800								7.49	1332		0.925		11.60*					(2, 59)
			10.92	1402								5.11	1072		1.314		9.49*					(2)
			11.50	1608																		(2)
	70	7.16	8.79	1406								4.50	1300		0.591		9.77*					(2, 20, 24, 59)
	12	10.68	11.38	1898								6.33	1673		0.759		11.53*					(60)
	30		12.97	1919	0.248							6.36	1794		1.132	1.315	14.78*					(2)
			11.92	1679																		(20)
		6.28	8.51	1311								4.36			0.661		8.21*					(2)
	12	10.39	12.78	2063								7.21			0.914		11.03*					(59)
			7.13	914																		(7, 58, 59)
			9.96	1146								5.57	819		1.273		10.57*					(20)
			11.71	1705								6.59	1322		1.476		14.57*					(2)
	30	8.16	10.97	1512								5.52	1287		0.858		11.38*					(2, 58, 59)
	12	8.61	11.88	1687								7.81	1413		0.844		12.65*					(2)
	40		11.51	1670	0.207							5.80	1652		1.087	1.172	14.92*					(2, 58, 59, 60)

1	2	3	4	5	6	7	8
516		<i>Eucalyptus loxophleba</i> , Benth.	York gum	W. Australia	Green	0.949	
517		<i>Eucalyptus macrorhyncha</i> , F. Muell.	Red stringybark	E. Australia	Air-dry		0.958
518		<i>Eucalyptus maculata</i> , Hook., f.	Spotted gum	New South Wales, Queensland	Green	0.726	0.877†
519		<i>Eucalyptus marginata</i> , Sm.	Jarrah, West Australian mahogany	W. Australia	Air-dry		0.715?
520		<i>Eucalyptus media</i> , Link.	Blackbutt	Australia	Green	0.727	0.787
521		<i>Eucalyptus microcorys</i> , F. Muell.	Tallowwood	New South Wales, Queensland	Air-dry		0.929†
522		<i>Eucalyptus microtheca</i> , F. Muell.	Coolibah	W. Australia	Green	0.834	
523		<i>Eucalyptus muelleriana</i> , A. W. Howitt	Yellow stringybark	Victoria	Air-dry		0.830?
524		<i>Eucalyptus nanglei</i> , R. T. B.	Pink ironbark	Australia	Air-dry		1.271
525		<i>Eucalyptus nitens</i> , J. H. M.	Scrub box, silvertop gum	New South Wales, Victoria	Green		1.170†
526		<i>Eucalyptus obliqua</i> , L'Hér	Stringybark	Australia, Tasmania	Australia	0.605	1.106†
527		<i>Eucalyptus paniculata</i> , Sm.	Grey ironbark	Australia	Green		1.127†
528		<i>Eucalyptus paniculata</i> , Sm. and <i>Eucalyptus crebra</i> , F. Muell.	Ironbark	New South Wales, Queensland	Air-dry	0.601?	
529		<i>Eucalyptus patens</i> , Benth.	Blackbutt	W. Australia	Green	0.905	0.915
530		<i>Eucalyptus patentinervis</i> , R. T. B.	Mahogany	New South Wales	Air-dry		0.772
531		<i>Eucalyptus pellita</i> , F. Muell.	Mahogany	Queensland	Green	0.915	1.058†
532		<i>Eucalyptus phellandra</i>	Messmate	Australia	Air-dry		0.994†
533		<i>Eucalyptus pilularis</i> , Sm.	Blackbutt	E. Australia	Green	0.687	0.738†
534		<i>Eucalyptus piperita</i> , Sm.	Sydney peppermint	E. Australia			0.918†
535		<i>Eucalyptus planchoniana</i> , F. Muell.	Tallow-wood	New South Wales, Queensland	Green	0.742	0.977†
536		<i>Eucalyptus platyphylla</i> , F. Muell.	Poplar gum	Australia	Air-dry		1.111†
537		<i>Eucalyptus polyanthemos</i> , Schau.	Red box	New South Wales, Victoria	Green	0.867	1.086†
538		<i>Eucalyptus propinqua</i> , H. D. and J. H. M.	Grey gum	New South Wales, Queensland	Air-dry		0.730?
539		<i>Eucalyptus punctata</i> , D. C.	Grey gum	New South Wales, Queensland	Green	0.989	1.015
540		<i>Eucalyptus raveretiana</i> , F. Muell.	Thozet's box, iron gum tree	Queensland	Air-dry		1.133†
541		<i>Eucalyptus redunca</i> , Schau.	Wandoo, white gum	W. Australia	Green	0.594	1.015
542		<i>Eucalyptus regnans</i> , F. Muell.	Giant gum, swamp gum	Victoria, Tasmania	Green	0.812	0.587?
543		<i>Eucalyptus resinifera</i> , Sm.	Red mahogany, forest mahogany	New South Wales, Queensland	Air-dry		0.802?
544		<i>Eucalyptus robusta</i> , Sm.	Swamp mahogany	E. Australia	Green	0.712	0.913†
545		<i>Eucalyptus rostrata</i> , Schl.	Murray red gum	E. Australia	Air-dry		0.701?
546		<i>Eucalyptus saligna</i> , Sm.	Blue flooded gum, Sydney blue gum	New South Wales, Queensland	Green	0.681	
547		<i>Eucalyptus saligna</i> , Sm. var. <i>pallidivalvis</i> , R. T. B. and H. G. S.	Flooded gum	New South Wales	Air-dry		0.672?
548		<i>Eucalyptus salmonophloia</i> , F. Muell.	Salmon gum	W. Australia	Green	0.897	0.802†
549		<i>Eucalyptus siderophloia</i> , Benth.	Broad-leaved ironbark, red ironbark	New South Wales, Queensland	Air-dry		0.944
550		<i>Eucalyptus sieberiana</i> , F. Muell.	Mountain ash	Australia	Green	0.771	1.161†
551		<i>Eucalyptus squamosa</i> , H. D. and J. H. M.	Ironwood, scaly-barked red gum	New South Wales			1.090†
552		<i>Eucalyptus stuartiana</i> , F. Muell.	Messmate, apple of Victoria	Victoria			1.208†
553		<i>Eucalyptus tereticornis</i> , Sm.	Forest red gum	E. Australia			1.082†
554		<i>Eucalyptus terminalis</i> , F. Muell.	Pale bloodwood	Australia			1.158†
555		<i>Eucalyptus tessellaris</i> , F. Muell.	Carbeen, Moreton Bay ash	S. Australia, N. S. W., Victoria, Tasmania			1.142†
556		<i>Eucalyptus viminalis</i> , Labill.	Ribbony gum, manna gum	Australia			0.974†
557		<i>Eucalyptus virgata</i> , Sieb.	{ Mountain ash Ironbark	Australia } Tasmania }			0.877†
558		<i>Eucalyptus wilkinsoniana</i> , R. T. B.	Small-leaved stringy-bark	New South Wales			0.882†
559		<i>Eugenia brachyandra</i> , J. H. M. and E. B.	Red apple	Australia			0.593†
560		<i>Eugenia coccinifera</i> , C. Moore	Coolamon	New South Wales			0.738†
561		<i>Eugenia cordata</i> , Laws	Waterbesje, um-Doni, Mutwa	S. Africa			0.700†

\* Tension parallel to grain.

† Bulk density calculated from weight and volume at time of test, no determination of moisture content having been made.



9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
	30	7.03	8.59	1054								5.38	861		0.802		8.02*					(20)
	12	7.73	10.19	1265								6.96	833		0.900		9.14*					
			9.80	1373								6.23	1598		1.498							(2, 59)
	61	6.82	8.71	1442								4.08	1167		0.647		10.95*					(2, 6, 20, 24, 52, 58, 59, 60)
	12	10.54	11.32	1968								5.52	1863		0.668		13.57*					
	50	5.83	7.45	1019								4.39	939		0.661		9.42*					(2, 20)
	12	7.24	10.54	1462								6.36	1050		0.738		10.90*					
		8.24	12.83	1427	0.272																	(3)
	48	7.59	9.14	1374								4.22			0.633		9.84*					(2, 6, 20, 24, 52, 58, 59, 60)
	12	10.68	12.02	1793								5.62			0.746		11.60*					
	13	8.40	10.06	1181	0.313	0.512					5.42	6.98	1185	4.07	1.905	2.341	9.47*		1700	1670	1930	(2, 16, 20)
			11.23									5.75					10.54*					(27)
			13.72	1912																		(2)
			9.99									5.54					12.75*					(27)
	72	4.92	6.61	1195								3.27	1090		0.577		9.42*					(2, 3, 20, 27, 51, 59)
	12	10.97	11.74	2548								5.59	1673		0.984		14.62*					
	24		12.48	1867	0.213							6.62	1645		1.289	1.376	8.86*					(2, 6, 59, 60)
	40	8.75	10.26	1530								5.45			0.787		10.54*					(20)
	12	13.00	13.64	2390								7.80			0.984		13.07*					
	61	5.62	7.38	1160								3.58	876		0.626		9.31*					(20)
	12	7.73	9.98	1406								5.94	927		0.795		11.04*					
			10.04	1403																		(2)
			7.13	1004																		(2)
			9.86	1100																		(61)
	33		11.08	1634	0.198							6.06	1498		1.052	1.157	11.35*					(2, 6, 7, 24, 52, 58, 59, 60)
			9.80	1653								4.62	1258		1.365		13.63*					(2, 58)
			14.12	1912																		(2)
			11.16	1182																		(24)
			11.39	1943								5.99	1648		1.259		15.76*					(58, 59)
	64	6.54	8.02	1237								4.96	1054		0.619		8.65*					(6, 20)
	12	10.48	11.24	1968								5.91	1371		0.731		12.23*					
	33		11.22	1625	0.190							6.32	1504		1.181	1.257	10.42*					(2, 60)
			8.36	869																		(24)
	28	8.26	9.84	1300								5.85	1188		0.809		10.09*					(20)
	12	9.60	11.32	1539								7.63	1231		0.921		11.32*					
	70	4.29	6.15	1265								2.95			0.492		10.54*					(2, 20)
	12	9.00	10.19	2320								5.06			0.738		13.63*					
	52	7.86	9.28	1371								4.31			0.647		10.90*					(2, 6, 20, 24, 49, 58, 60)
	12	10.19	11.60	1897								6.01			0.689		14.34*					
			9.18	1388								5.02	1207		1.100		10.82*					(2, 58, 59)
	40	3.58	4.78	521								2.64			0.710		4.98*					(2, 20, 59)
	12	6.75	7.31	990								3.80			1.027		6.29*					
	67	6.89	8.22	1301								4.39	1090		0.619		10.87*					(2, 20, 24, 58, 59, 60)
	12	10.90	11.39	1877								6.01	1850		0.773		13.29*					(2)
			12.92	1822																		
	25	8.86	11.60	1477								5.69	910		0.851		11.88*					(20)
	12	10.54	14.13	1758								7.52	1054		1.336		13.50*					
			12.18	1649								5.83	1170		1.112		10.33*					(2, 24, 52, 59)
	34		12.24	1652	0.177							5.67	1234		0.546	0.586	9.80*					(2, 60)
			4.47	641																		(2)
			5.72	722																		(24)
			10.44	1292								6.09	1286		1.433		10.72*					(2, 24, 59)
			10.62	1134																		(24)
			10.03	1028																		(24)
			8.30	1262								3.92	875		0.936		9.32*					(2, 27, 59)
			8.76	1481								5.32	1268		1.483		12.24*					(2, 58, 59)
			13.58	1793																		(2)
			8.04	1193																		(61)
			8.26	1307																		(2)
		2.18	5.58	869	0.032							3.79										(12)

1	2	3	4	5	6	7	8
562		<i>Eugenia cotinifolia</i> , Jacq.	Clou	Mauritius			0.978†
563		<i>Eugenia jambolana</i> , Lam.	Jaman, black plum, Thabye	India			0.769†
564		<i>Eugenia maire</i> , A. Cunn.	Maire	New Zealand			0.790†
565		<i>Eugenia maire</i> , A. Cunn. var. ?	Black Maire	New Zealand			1.159†
566		<i>Eugenia ridleyi</i> , King.	Kelat	Fed. Malay States	Air-dry		0.689
567		<i>Eugenia</i> sp.	Pomme	Mauritius			0.547†
568		<i>Leptospermum ericoides</i> , A. Rich.	Manuka, tea tree	New Zealand			0.943†
569		<i>Melaleuca maideni</i> , R. T. B.	Bellbowrie tea tree	Queensland			0.754†
570		<i>Melaleuca styphelioides</i> , Sm.	Prickly-leaved tea tree	New South Wales, Queensland			1.074†
571		<i>Metrosideros robusta</i> , A. Cunn.	Northern Rata	New Zealand			1.045†
572		<i>Planchonia andamanica</i> , King.	Red Bambwe	India			
573		<i>Rhodamnia argentea</i> , Benth.	Silver myrtle	New South Wales			0.817†
574		<i>Syncarpia laurifolia</i> , Ten.	Turpentine	New South Wales	Green	0.672	
575		<i>Tristania conferta</i> , R. Br.	Brush box	N. Australia, New South Wales	Air-dry Green	0.738	0.672
576		<i>Tristania laurina</i> , R. Br.	Water gum	E. Australia			0.730?
577		<i>Tristania suaveolens</i> , Sm.	Swamp mahogany	New South Wales			0.962†
578	Ochnaceae	<i>Lophira procera</i> , A. Chev.	Ironwood, Kaku, Ekki	W. Africa	Air-dry		0.905†
579	Oleaceae	<i>Scorodocarpus borneensis</i> , Becc.	Kulim	Fed. Malay States	Air-dry		0.930
580		<i>Strombosia javanica</i> , Bl.	Dedali	Fed. Malay States	Green	0.593	0.737
581	Oleaceae	<i>Fraxinus excelsior</i> , Linn.	Ash	British Isles	Air-dry		
582		<i>Noronhia broomeana</i> , Horne	Sandal	Mauritius			0.891†
583		<i>Notelaea ligustrina</i> , Vent.	Silkwood	New South Wales, Victoria, Tasmania			1.043†
584		<i>Olea foveolata</i> , E. Mey.	Bastard ironwood, Ijzerhout, Maro- chani	S. Africa			1.010†
585		<i>Olea hochstetteri</i> , Baker	Musharagi	E. Africa	Air-dry	0.802	0.825
586		<i>Olea laurifolia</i> , Lam.	Black ironwood, Regte Zwarte Ijzer- hout, Igqwanxe	S. Africa			0.897
587		<i>Olea verrucosa</i> , Link.	Wild olive, Olyvenhout, um-Ngquma	S. Africa			1.122†
588	Oliniaceae	<i>Olinia cymosa</i> , Thunb.	Mountain hard pear, red berry, Sat- yobe	S. Africa			0.890†
589	Palmae	<i>Borassus flabellifer</i> , Linn.	Tāl, Tan, The Toddy, Palmyra palm	India			0.802†
	Pinaceae, v. Coniferae						
590	Pittosporaceae	<i>Bursaria spinosa</i> , Cav.	Native box	Australia			0.871†
591		<i>Bursaria spinosa</i> , Cav. var. ?	Prickly box	Australia			0.922†
592		<i>Pittosporum tenuifolium</i> , Gaertn.	Birch, Mapau	New Zealand			0.965†
593	Proteaceae	<i>Banksia integrifolia</i> , Linn.	White honeysuckle	Australia			0.577†
594		<i>Banksia serrata</i> , Linn.	Red honeysuckle	Australia			0.802†
595		<i>Banksia verticillata</i> , R. Br.	River Banksia	W. Australia	Green	0.473	0.501
596		<i>Embothrium wickhami</i> , Hill and F. Muell.	Satin silky oak	Australia			0.529†
597		<i>Grevillea hilliana</i> , F. Muell.	Red silky oak	New South Wales, Queensland			0.994†
598		<i>Grevillea robusta</i> , A. Cunn.	Silky oak	Australia			0.641†
599		<i>Knightia excelsa</i> , R. Br.	Honeysuckle, Rewa Rewa	New Zealand			0.785†
600		<i>Orites excelsa</i> , R. Br.	Silky oak	Australia			0.593†
601		<i>Stenocarpus salignus</i> , R. Br.	Beef wood	New South Wales, Queensland			0.817†
602		<i>Stenocarpus sinuatus</i> , Endl.	Fire-tree	Australia			0.738†
603		<i>Xylomelum occidentale</i> , R. Br.	Native pear	W. Australia	Green	0.628	0.658 (12 % M. C.)
604	Rhamnaceae	<i>Alphitonia excelsa</i> , Reiss.	Red ash	Queensland			0.737†
605		<i>Emmenosperma alphitonioides</i> , F. Muell.	Bone-wood	New South Wales, Queensland			0.849†
606		<i>Rhamnus zeyheri</i> , Sond.	Red ivory, um-Nini, Niere	S. Africa		0.806	0.925
607		<i>Zizyphus jujuba</i> , Lam.	Jujube tree, Hauthai, Bér, Bogri	India			0.784†
608	Rhizophoraceae	<i>Anisophyllea laurina</i> , R. Br.	Monkey apple	W. Africa	Air-dry		0.708
609		<i>Bruguiera gymnorrhiza</i> , Lam.	Bakau Minyak	Fed. Malay States	Green	0.937	
610		<i>Bruguiera rheedii</i> , Bl.	Black or red mangrove	Australia			0.865†
611		<i>Carallia calycina</i> , Benth.	Ubberiya	Ceylon			0.909†
612		<i>Carallia integerrima</i> , DC.	Dawata, Kierpa, Maniawga, Andi	Ceylon			0.749†
613		<i>Weihea africana</i> , Benth.	Musaizi	E. Africa			0.685
614	Rosaceae	<i>Leucosidea sericea</i> , Eckl. and Zeyh.	Oudehout, Dwa-dwa, um-Chicki	S. Africa	Air-dry		0.610†
615		<i>Parinarium</i> sp.	Muntelot	Fed. Malay States	Green Air-dry	0.729	
616		<i>Pygeum africanum</i> , Hook., f.	Bitter almond, red stinkwood, Dumi- zulu, Mueri	S. Africa		0.796	0.845
617	Rubiaceae	<i>Adina cordifolia</i> , Hook., f.	Haldu, Hnaw, Bansa	India			0.721†
618		<i>Antirrhoea verticillata</i> , DC.	Loustau	Mauritius			0.614†

\* Tension parallel to grain.

† Bulk density calculated from weight and volume at time of test, no determination of moisture content having been made.



9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
		5.38	16.77	1549								7.05			1.381							
			7.59	839								6.21										
		5.36	9.09	861	0.199																	(31, 43)
		9.77	15.90	1327	0.413																	(3, 28)
	16	5.64	11.57	1976																		(3)
		3.95	6.64	756																		(21)
		5.82	12.10	1164	0.165							3.97			0.695							(63)
			6.99	899																		(3)
			11.26	1367																		(61)
																						(61)
		4.71	9.92	1188	0.139																	(3)
			8.26									3.85			1.378							(9)
			12.15	1416																		(61)
	74	5.83	7.33	1195								3.98	984		0.548		8.43*					(2, 6, 20, 24, 58, 59, 60)
	12	9.70	10.41	1652								5.38			0.766		11.74*					
	65	6.47	7.91	1143								3.48	1364		0.633		9.04*					(2, 20, 24, 60)
	12	10.33	11.04	1743								5.20			0.843		11.74*					(61)
			9.56	1458																		(2, 24)
			7.54	827																		(11, 18)
	17	9.73	16.08	1919	0.250	2.355					5.96	7.35	1921	1.701	1.640	1.863	0.861	1.324	1952	1727	1727	(21)
	16	4.57	8.41	1336																		(21)
	40	3.94	7.83	1336																		(5)
		3.76	11.53	1287								5.86										(63)
		6.44	10.18	1300								6.26			0.324							(3)
		5.67	13.15	1099	0.184																	
		5.46	9.79	1613	0.109							7.08										(12)
	14		6.47									7.46			0.682							(22)
	50																					
0.940	10	6.66	11.45	1460	0.183							7.16			0.769							(

1	2	3	4	5	6	7	8
619		<i>Mitragyna macrophylla</i> , Hiern.	Subaha, Ya-ya, Abura	W. Africa	Air-dry		0.503
620		<i>Plectronia mundtii</i> , Poepp.	Rock alder, Klip Esse, Sandulane	S. Africa			0.830†
621		<i>Sarcocephalus esculentus</i> , Afzel.	Opepe, Kusiaba	W. Africa			0.806†
622	<i>Rutaceae</i>	<i>Acronychia baueri</i> , Schott.	Brush ash	New South Wales, Queensland			0.849†
623		<i>Calodendron capense</i> , Thunb.	Wild chestnut, Kastanjehout, Moeh-akalela, um-Baba	S. Africa			0.620†
624		<i>Clausena inaequalis</i> , Benth.	um-Nukambiba	S. Africa			0.800†
625		<i>Flindersia acuminata</i>	Putt's pine	Australia			0.577†
626		<i>Flindersia australis</i> , R. Br.	Colonial teak, crow's ash	New South Wales, Queensland	Green	0.747	
627		<i>Flindersia bennettiana</i> , F. Muell.	She-teak	New South Wales, Queensland			0.850†
628		<i>Flindersia chatawaiana</i> , F. M. Bailey	Queensland maple	Queensland			0.689†
629		<i>Flindersia iflaiana</i> , F. Muell.	Cairn's hickory, Queensland hickory	Queensland			0.928†
630		<i>Flindersia ozleyana</i> , F. Muell.	Long jack	New South Wales, Queensland			0.737†
631		<i>Murraya exotica</i> , Linn.	Satinwood, Marchula	India			0.994†
632		<i>Toddalia lanceolata</i> , Lam.	White ironwood, Maroogoo, um-Zani	S. Africa		0.715	0.787
633		<i>Xanthoxylum thunbergii</i> , DC.	Knobthorn, Knopjsedoorn, um-Nungumabele	S. Africa			0.940†
634	<i>Salicaceae</i>	<i>Populus</i> spp.	Poplar	British Isles	Air-dry		
635		<i>Salix caprea</i> , Linn.	Willow	British Isles			0.490†
636	<i>Sapindaceae</i>	<i>Alectryon excelsum</i> , Gaertn.	Titoki	New Zealand			0.816†
637		<i>Allophylus zeylanicus</i> , Linn.	in-Quala	S. Africa			0.750†
638		<i>Blighia</i> sp.	Ukpc-Nikwi	W. Africa			1.148†
639		<i>Cupania anacardioides</i> , A. Rich.	Carrot-wood, Tuckeroo	New South Wales, Queensland			0.833†
640		<i>Diploglottis cunninghamii</i> , Hook., f.	Native tamarind	New South Wales, Queensland			0.641†
641		<i>Harpullia pendula</i> , Planch.	Tulip wood	New South Wales, Queensland			0.930†
642		<i>Hippobromus alata</i> , Eckl. and Zeyh.	Paardepis, Ulwatile, u-Qume	S. Africa			0.990†
643		<i>Ratonia tenax</i> , Benth.	Brush teak	New South Wales, Queensland			0.738†
644		<i>Sapindus trifoliatus</i> , Linn.	Soapnut, Ritha	India			1.026†
645	<i>Sapotaceae</i>	<i>Bassia</i> sp.	Belian	Fed. Malay States	Air-dry		0.904
646		<i>Dichopsis petiolaris</i> , Thw.	Tawenna	Ceylon			0.739†
647		<i>Dichopsis</i> sp.	Mai-aug	Fed. Malay States	Air-dry		0.612
648		<i>Imbricaria maxima</i> , Poir.	Nyatoh	Fed. Malay States	Air-dry		0.569
649		<i>Mimusops caffra</i> , E. Mey.	Natte	Mauritius			0.848†
650		<i>Mimusops elengi</i> , Linn.	Red milkwood, Chole, um-Tunzi	S. Africa			0.850†
651		<i>Mimusops littoralis</i> , Kurz.	Bukal, Mulsari, Kaya	India			0.961†
652		<i>Mimusops obovata</i> , Sond.	Andaman bullet-wood, Dogala, Mowha, Katpali	India			1.058†
653		<i>Mimusops</i> sp.	Red milkwood, um-Tunzi, Amasetole	S. Africa			0.910†
654		<i>Payena utilis</i> , Ridl.	Baku	W. Africa	Air-dry		0.623
655		<i>Sideroxylon grandiflorum</i> , A. DC.	Belian, Betis	Fed. Malay States	Air-dry		1.002
656		<i>Sideroxylon inerme</i> , Linn.	Tambalacoque	Mauritius			0.883†
657	<i>Saxifragaceae</i>	<i>Anopterus glandulosus</i> , Labill.	White milkwood, Witte Melkhout, um-Qwashu	S. Africa			0.990†
658		<i>Carpodetus serratus</i> , Forst.	Native laurel	Australia			0.750†
659	<i>Scrophulariaceae</i>	<i>Halleria lucida</i> , Linn.	White Mapau	New Zealand			0.822†
660	<i>Sonneratiaceae</i>	<i>Duabanga sonneratioides</i> , Ham.	um-Binza	S. Africa			0.910†
661		<i>Sonneratia</i> sp.	Kokan, Lampatia	India	Air-dry		0.461
662	<i>Sterculiaceae</i>	<i>Commersonia echinata</i> , Forst.	Perepat	Fed. Malay States	Green	0.657	
663		<i>Dombeya mastersii</i> , Hook.	Kurrajong	Australia			0.465†
664		<i>Heritiera fomes</i> , Buch.	Mukao	E. Africa	Air-dry		0.527
665		<i>Heritiera littoralis</i> , Dryand.	Sundri, Pinlékanazo, Mawldá	India			1.074†
666		<i>Pterospermum suberifolium</i> , Lam.	Looking-glass tree, Chomuntri, Sundri, Pinlékanazo	Ceylon			1.209†
667		<i>Sterculia tragacantha</i> , Lindl.	Vuinaku, Vincol	Ceylon			0.648†
668		<i>Tarrietia trifoliolata</i> , F. Muell.	Okoko	W. Africa			0.822†
669		<i>Tarrietia utilis</i> , Hiern.	Stavewood	Australia	Air-dry		0.838
670		<i>Triplochiton johnsoni</i> , C. H. Wright	Attabini, Niankuma	W. Africa	Air-dry		0.497
671	<i>Symplocaceae</i>	<i>Symplocos grandiflora</i> , Wall.	Owawa, Obeche, Arcere	W. Africa	Oven-dry		
672	<i>Tiliaceae</i>	<i>Berria ammonilla</i> , Roxb.	Bumroti, Moat soom	India			
673		<i>Echinocarpus australis</i> , Benth.	Halmilla, Petwun, Trincomalee wood	Ceylon			0.801†
674		<i>Entelea arborescens</i> , R. Br.	Maiden's blush	Australia			0.513†
675		<i>Grewia occidentalis</i> , Linn.	Corkwood	New Zealand			0.189†
676	<i>Ulmaceae</i>	<i>Aphananthe philippinensis</i> , Planch.	Kruisbesje, um-Nqabaza	S. Africa			0.730†
677		<i>Celtis rhamnifolia</i> , Prest.	Native elm, Australian hickory	Queensland, New South Wales			0.737†
			Kamdeboo, stinkhout, um-Vumvu, Witgalboom	S. Africa		0.636	0.699

\* Tension parallel to grain.

† Bulk density calculated from weight and volume at time of test, no determination of moisture content having been made.



[illegible]

1	2	3	4	5	6	7	8
678		<i>Chaetachme aristata</i> , Planch.	um-Kovoti	S. Africa			0.780†
679		<i>Trema guineensis</i> , Priemer	Pigeon wood, um-Bengele	S. Africa			0.450†
680		<i>Ulmus</i> spp.	Elm	British Isles	Air-dry		
681	<i>Umbelliferae</i>	<i>Heteromorpha arborescens</i> , Cham. and Schl.	um-Bangandhlala	S. Africa			0.870†
682	<i>Urticaceae</i>	<i>Villebrunea integrifolia</i> , Gaud.	Ban kotkora, Lipie	India			
683	<i>Verbenaceae</i>	<i>Avicennia officinalis</i> , Linn.	Grey mangrove	Australia			0.849†
684		<i>Clerodendron glabrum</i> , E. Mey.	um-Qwaqwana	S. Africa			0.690†
685		<i>Gmelina arborea</i> , Roxb.	Yamane, Gamhar	India			0.577†
686		<i>Gmelina leichhardtii</i> , F. Muell.	White beech	Australia			0.787†
687		<i>Tectona grandis</i> , Linn., f.	Teak, Saka, Sáj, Ságun	India	Green	0.581	
					Air-dry		0.582
					Oven-dry		
688		<i>Vitex altissima</i> , Linn.	Milla, Nemili-adagu, Maila	India			0.977†

\* Tension parallel to grain. † Bulk density calculated from weight and volume at time of test, no determination of moisture content having been made.

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(For a key to the periodicals see end of volume)

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## DANISH WOODS

E. SUENSON

For testing methods, see the original literature

Index No.	Genus and species	Local name	Bulk density, air-dry	Moisture content	Static bending			Compression		Lit.
					Fiber stress at elastic limit	Modulus of rupture	Modulus of elasticity	Parallel to grain	Perpendicular to grain	
								Maximum crushing strength	Fiber strength at elastic limit	
			g/cm <sup>3</sup>	% of oven-dry wt.				kg/mm <sup>2</sup>	kg/mm <sup>2</sup>	
690	<i>Abies pectinata</i>	Ædelgran	0.440	15				3.60		(2)
691	<i>Picea abies</i> L. *	Rødgran	0.430	18	3.23	5.57	880	2.95	0.00	(3)
			0.474	15	4.06					(1, 2)
692	<i>Pinus laricio</i> v. <i>Austriaca</i> , Endl.	Østerrigsk Fyr	0.506	14.2				2.93		(2)
693	<i>Pinus montana</i> , Mill.	Bjærgfyr	0.487-0.564	12.4				2.97-5.56		(2)
694	<i>Pseudotsuga Douglasii</i> , Carr.	Douglasie	0.490	15				3.24		(2)
695	<i>Quercus robur</i> , L. †	Eg	0.740	17	3.94	8.53	910	4.20	0.58	(3)

\* Tensile strength, 4.30-7.80 kg/mm<sup>2</sup> with 33-49 % moisture content (1).

† *Quercus pedunculata*, Ehrh. = *Quercus sessiliflora*, Sm.

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9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0.570-0.794		2.11	5.58	826	0.032							4.29										(12)
		1.88	4.65	739	0.030							3.81										(12)
		4.86	9.97	1470								7.10					9.56*					(1, 5, 25)
		3.05	5.97	888	0.060							3.81										(12)
			5.40	583								3.19			0.855							(10)
0.599			9.27	1194																		(61)
		2.34	6.23	521	0.058							3.86										(12)
			7.45	1044								4.03			0.851							(9, 31)
			5.39	1006								4.68	960		1.211		6.28*					(59, 61)
	56	4.73	7.63	1093	0.116		11.15	1434	0.487	84	2.75	3.88	1291	0.734	0.721	0.828	0.399	0.508	405	450	449	(10, 31, 32, 38, 43)
	12	6.09	9.04	1195	0.176		12.75	1605	0.564	65	3.37	5.37	1317	0.969	0.939	0.920	0.391	0.502	456	467	485	
	9	6.74	10.19	1243	0.209		12.74	1781	0.512	74	3.64	5.86	1242	1.124	0.884	1.030	0.590	0.734	474	477	535	
		5.74	10.38	1136	0.161							4.91			0.706							(54)

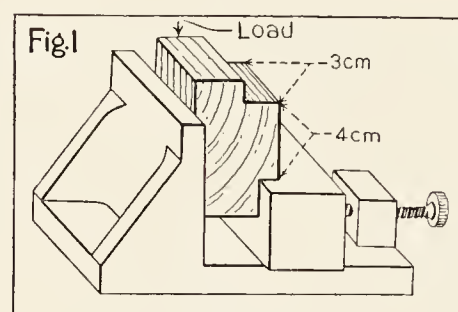
## WOODS OF THE DUTCH EAST-INDIAN ARCHIPELAGO

THE FOREST RESEARCH INSTITUTE, BUITENZORG, JAVA

The values recorded below were determined in the Forest Research Institute in accordance with the standard testing methods of the "IV Kongress des Internationalen Verbandes für die Materialprüfungen, Brussels, September 1906," except in the following minor points:

1. The rate of strain increase in the bending and compression tests was 50 instead of 20 kg/cm<sup>2</sup> per minute.
2. The test piece shown in the figure was used in the shear tests.

The values given are the average for 4 to 10 specimens from two or more trees of different localities, except in the case of *Swietenia mahogani* Jack. and *Tectona grandis* L., cultivated in Java, for which 30 to 40 tests were made. All specimens tested were air-dried to the average moisture content shown.



Shearing test.

Index No.	Botanical name		Local name	Bulk density, air-dry,	Moisture content, air-dry	Static bending					Compression parallel to grain			Shear		Hardness
	Family	Genus and species				Fiber stress at elastic limit	Modulus of rupture	Modulus of elasticity	Work to elastic limit	Work to maximum load	Fiber stress at elastic limit	Maximum crushing strength	Modulus of elasticity	Radial	Tangential	
				g/cm <sup>3</sup>	% oven-dry	kg/mm <sup>2</sup>			kg-mm/mm <sup>3</sup>		kg/mm <sup>2</sup>					kg/cm <sup>2</sup>
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
700	Anacardiaceae	<i>Buchanania arborescens</i> , Bl.	Popohan	0.48	16	3.20	6.83	900	0.0006	0.00593	1.74	3.47	930	0.67	0.78	431
701		<i>Gluta Renghas</i> , L.	Rengas	0.64	14	3.70	6.04	1260	.00027	.00333	3.30	4.74	1190	0.87	0.92	514
702	Apocynaceae	<i>Alstonia scholaris</i> , R. Br.	Pulaj	0.31	15	1.72	3.46	530	.00033	.00207	1.16	2.21	550	0.38	0.55	192
703	Casuarinaceae	<i>Casuarina equisetifolia</i> , Forst.	Chemara	0.71	19	5.70	9.55	1440	.00127	.00633	3.16	5.41				763
704	Dipterocarpaceae	<i>Dipterocarpus</i> sp.	Lagan, Kruing	0.68	15	4.99	8.79	1450	.00096	.00545	3.47	5.68		1.02	0.98	575
705		<i>Dryobalanops camphora</i> , Colebr.	Kapur	0.68	15	6.49	11.10	1585	.00147	.00814	4.31	6.18	1960	0.92	1.17	575
706		<i>Dryobalanops oblongifolia</i> , Dyer.	Petanang	0.66	16	5.67	9.71	1520	.00137	.00817	3.44	4.88	1550	0.86	1.09	545
707		<i>Dryobalanops oicarpa</i> , v. Sl.	Sintok	0.50	14	2.55	4.66	1097	.00047	.00447	2.07	3.76		0.69	0.70	316
708		<i>Hopea Mengerawan</i> , Miq.	Merawan	0.57	14	6.35	8.00	1495	.00186	.00974	3.06	5.04	1400	0.68	0.87	583
709		<i>Hopea</i> sp.	Bankirai	0.72	17	7.88	11.69	1624	.00220	.00773	4.21	6.62	1795	0.99	1.15	686
710		<i>Shorea Balangeran</i> , Burek.	Belangiran	0.73	17	5.00	9.95	1212	.00113	.01053	3.16	5.09	1523	0.74	0.75	521
711		<i>Shorea</i> sp.	Banio	0.47	17	2.69	4.61	1030	.00040	.00507	1.53	3.83		0.54	0.44	286
			Damar merah	0.31	15	2.85	4.25	897	.00053	.00173	1.42	2.96				166
			Simantok	0.78	16	6.17	11.12	1565	.00153	.01093	3.80	5.79		1.08	1.35	630
712		<i>Vatica</i> sp.	Resak, Giam	0.79	16	6.42	10.60	1300	.00173	.00760	3.75	6.10	1585	1.15	1.24	871

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
713	Flacourtiaceae	<i>Homalium tomentosum</i> , Bth.	Dlingsem	0.81	16	5.90	12.50	1410	.00140	.01467	3.47	6.32	1560	1.03	1.41	1122
714	Hamamelidaceae	<i>Altingia excelsa</i> , Nor.	Rasamala	0.75	18	5.66	9.76	1365	.00130	.00730	3.20	5.72	1535	0.91	1.13	546
715	Lauraceae	<i>Eusideroxylon Zwageri</i> , T. et B.	Ijzerhout,	0.85	15	7.88	13.89	1522	.00227	.01147	4.03	7.46	1650	1.01	1.44	1120
			Onglenbelian													
716	Leguminosae	<i>Dalbergia latifolia</i> , Roxb.	Sono kling,	0.75	14	5.35	13.27	1387	.00120	.01567	3.15	6.36	1508	1.22	1.16	953
			Java-palis-													
			sander													
717		<i>Intsia amboinensis</i> , Thouars.	Merbau, Ipil	0.80	14	8.37	14.54	1840	.00233	.01202	3.78	8.19				963
718	Meliaceae	<i>Swietenia macrophylla</i> , King.	Mahogany	0.54	15	4.57	6.73	817	.00147	.00433	2.55	4.27	853	0.92	0.87	530
719		<i>Swietenia mahogani</i> , Jack.	Mahogany	0.54	14	4.66	7.10	890	.00147	.00493	2.20	4.04	925	0.83	0.98	435
720		<i>Toona Suren</i> , Merr.	Suren	0.38	15	3.46	5.47	860	.00077	.00340	2.05	3.44	790	0.68	0.80	323
721	Moraceae	<i>Artocarpus elastica</i> , Reinw.	Bendo	0.35	15	3.06	4.47	810	.00067	.00341	1.52	2.92	735	0.47	0.48	260
722	Olcaceae	<i>Scorodocarpus borneensis</i> , Becc.	Kulim	0.81	16	6.33	12.48	1552	.00137	.01060	3.49	6.67	1732	0.86	1.27	887
723	Rhizophoraceae	<i>Combretocarpus Motleyi</i> , Hook. f.	Mrapat	0.67	16	3.86	6.95	1237	.00073	.00507	2.05	4.82	1060	1.00	0.81	475
724	Sapindaceae	<i>Schleichera oleosa</i> , Merr.	Kesambi	0.88	16	6.11	11.56	1680	.00133	.00893	3.07	5.91	1490	1.15	1.79	1428
725	Sterculiaceae	<i>Pterospermum javanicum</i> , Jungh.	Bajur	0.44	17	4.45	7.55	920	.00120	.00833	2.63	3.68	1095	0.56	0.74	382
726	Taxaceae	<i>Podocarpus imbricata</i> , Bl.	Aruh, Djamud-	0.45	17	3.80	5.89	647	.00133	.00433	1.65	3.14				355
			juh ki chemara													
727	Theaceae	<i>Schima Noronhae</i> , Reinw.	Puspah, Seru	0.60	16	5.81	10.00	1488	.00133	.01056	3.34	5.49	1644	0.81	1.05	505
728	Tiliaceae	<i>Actinophora fragrans</i> , R. Br.	Walikukun	0.85	18	6.83	14.52	1520	.00172	.01974	4.26	7.10	1930	1.24	1.56	1220
729	Ulmaceae	<i>Celtis Wightii</i> , Planch.	Pendjalinan	0.72	16	4.20	11.60	1420	.00070	.02151	2.34	4.96	1590	1.13	1.31	775
730	Verbenaceae	<i>Tectona grandis</i> , Lin. f.	Djati, teak	0.59	14	5.75	8.90	1410	.00193	.01000	3.00	4.90	1316	0.82	0.97	396
731		<i>Vitex pubescens</i> , Vahl.	Laban	0.70	16	7.47	12.72	1510	.00207	.01040	4.69	6.84	1660	1.07	1.15	795

## WOODS OF JAPAN AND EASTERN ASIA

HOMI SHIROSAWA

The values recorded below are based on tests made in the Central Forest Experiment Station (Ringyo-Shikenjo), Meguro, Tokyo, Japan.

The equations expressing the relation between the density and the stress were derived from the bulk density of air-dried specimens (moisture content, 16 %) and the green and oven-dry densities, given in the column "bulk density," are based on the volume in the air-dry condition (moisture content, 16 %).

The testing methods employed were those described above under "Woods of North America," with the following exceptions:

**Static Bending.**—Specimen 6 × 6 × 48 cm, 42 cm span mainly (85 % of all specimens); 0.1 cm per min.

**Compression Parallel to Grain.**—Specimen 6 × 6 × 6 cm mainly (83 % of all specimens); 0.1 cm per min.

**Compression Perpendicular to Grain.**—Specimen 6 × 6 × 6 cm mainly (85 % of all specimens); 0.1 cm per min.

**Shear Parallel to Grain.**—Shear over a 9 × 4 cm area; 0.1 cm per min.

**Tension Parallel to Grain.**—Tension over a 2.25 cm area; 0.1 cm per min.

**Hardness.**—Specimen 6 × 6 × 6 cm. Depth of indentation when the steel cylinder with 3 cm diameter hemispherical end is forced into the specimen with the load of 2000 kg against radial and tangential surfaces, and with 4000 kg against end surface.

Den unten angegebenen Werten liegen Prüfungen zu Grunde, welche im Central Forest Experiment Station (Ringyo-Shikenjo) Meguro, Tokyo, Japan, gemacht worden sind.

Die Gleichungen, welche die Beziehung zwischen Dichte und Druck enthalten sind aus der durchschnittlichen Dichte des lufttrockenen Materials abgeleitet. (Feuchtigkeitsgehalt 16 %) und die Dichten des frischen und ofentrockenen Materials, die in der Kolonne "bulk density" stehen, gründen sich auf den lufttrockenen Zustand (Feuchtigkeitsgehalt 16 %).

Die angewendeten Prüfungsmethoden waren die gleichen, welche unter "Woods of North America" angegeben sind. Mit Ausnahme:

**Statischer Biegeversuch.**—Muster 6 × 6 × 48 cm durchschnittliche Spannweite 42 cm (85 % aller Muster); 0,1 cm in der Min.

Les valeurs mentionnées ci-dessous sont basées sur des essais effectués à la Central Forest Experiment Station (Ringyo Shikenjo) Meguro, Tokio, Japon.

Les équations exprimant la relation entre la densité et la tension ont été déduites de la densité apparente d'éprouvettes séchées à l'air (teneur en humidité, 16 %), et les densités du bois vert et du bois séché au four, donnés dans la colonne "bulk density" sont basées sur le volume de l'éprouvette séchée à l'air (teneur en humidité, 16 %).

Les méthodes d'essais employées sont celles déjà décrites dans "Bois de l'Amérique du Nord" à l'exception des suivantes:

**Essai de flexion statique.**—Eprouvette 6 × 6 × 48 cm, portée principalement 42 cm (85 % de toutes les éprouvettes); 0,1 cm par minute.

**Compression parallèle à la fibre.**—Eprouvette 6 × 6 × 6 cm principalement (83 % de toutes les éprouvettes); 0,1 cm par minute.

**Compression perpendiculaire à la fibre.**—Eprouvette 6 × 6 × 6 cm principalement (85 % de toutes les éprouvettes); 0,1 cm par minute.

**Cisaillement parallèle à la fibre.**—Cisaillement sur une surface de 9 × 4 cm; 0,1 cm par minute.

**Traction parallèle à la fibre.**—Traction sur une surface de 2,25 cm<sup>2</sup>; 0,1 cm par minute.

**Dureté.**—Eprouvette 6 × 6 × 6 cm. Profondeur de l'empreinte produite par un cylindre d'acier terminé par un hémisphère de 3 cm de diamètre forcé dans l'éprouvette avec une charge de 2000 kgs contre la surface radiale et tangentielle, et de 4000 kgs contre la surface terminale.

I valori qui sotto riportati sono stati dedotti da prove eseguite nella Central Forest Experiment Station (Ringyo-Shikenjo), Meguro, Tokyo, Giappone.

Le equazioni che esprimono la relazione fra la densità e la pressione sono derivate dalla densità (volumetrica) del materiale asciugato all'aria (con 16 per cento d'acqua): le densità del materiale greggio e quello asciugato alla stufa, i quali si trovano nella colonna "bulk density," sono fondate sul volume del materiale asciugato all'aria (il tenuto d'acqua essendo 16 per cento).

I metodi impiegati per i saggi sono gli stessi riportati nel capitolo "Legni dell'America del Nord" fatta eccezione per quanto segue:

**Flessione statica.**—Provetta 6 × 6 × 48 cm, distanza media tra gli appoggi 42 cm (85 % di tutti i campioni); 0,1 cm al minuto.



**Druck parallel zur Faserrichtung.**—Muster  $6 \times 6 \times 6$  cm hauptsächlich (83 % aller Muster); 0,1 cm in der Min.

**Druck senkrecht zur Faserrichtung.**—Muster  $6 \times 6 \times 6$  cm hauptsächlich (85 % aller Muster); 0,1 cm in der Min.

**Scherversuch parallel zur Faserrichtung.**—Scherung über  $9 \times 4$  cm, 0,1 cm in der Min.

**Zug parallel zur Faserrichtung.**—Zug über eine Fläche von 2,25 cm<sup>2</sup>, 0,1 cm in der Min.

**Härte.**—Muster  $6 \times 6 \times 6$  cm. Eindruckstiefe eines Stahlzylinders mit halbkugelförmigem Ende (Durchmesser 3 cm) beobachtet, bei Belastung mit 2000 kg gegen die radiale und tangential Oberfläche und mit 4000 kg gegen die Endfläche.

**Compressione parallela alla fibra.**—Provetta  $6 \times 6 \times 6$  cm per la massima parte (83 % di tutti i campioni); 0,1 cm al minuto.

**Compressione perpendicolare alla fibra.**—Provetta  $6 \times 6 \times 6$  cm per la massima parte (85 % di tutti i campioni); 0,1 cm al minuto.

**Taglio nel senso della fibra.**—Taglio sopra  $9 \times 4$  cm; 0,1 cm al minuto.

**Trazione nel senso della fibra.**—Trazione sopra una superficie di cm<sup>2</sup> 2,25; 0,1 cm al minuto.

**Durezza.**—Provetta  $6 \times 6 \times 6$  cm. Profondità di impronta di un cilindro di acciaio con estremità emisferica (diametro 3 cm) osservata caricando con 2000 kg contro la superficie radiale e tangenziale e con 4000 contro la superficie terminale.

## STRENGTH AND RELATED PROPERTIES

Index No.	Botanical name		Local name	Bulk density			Moisture content green, %	Static bending				Compression parallel to grain—maximum crushing strength	Compression perpendicular to grain	Shear parallel to grain	Tension parallel to grain	Hardness		
	Family	Genus and species		Green	Air-dry	Oven-dry		Fiber stress at elastic limit	Modulus of rupture	Modulus of elasticity	Work to elastic limit					End	Radial	Tangential
				g/cm <sup>3</sup>			kg/mm <sup>2</sup>	kg-mm/mm <sup>3</sup>		kg/mm <sup>2</sup>					cm			

## I. Equations expressing strength in terms of density

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
									$F = 6.50 D_a^{1.20}$	$F = 10.10 D_a^{1.20}$	$F = 1350 D_a^1$	$F = 0.0053 D_a^2$	$F = 7.00 D_a^1$	$F = 2.31 D_a^2$	$F = 1.34 D_a^1$	$F = 8.64 D_a^1$	Actual value given below	Actual value given below	Actual value given below

## II. Values as determined by tests—strength values expressed in percentage of equation values

751	<i>Aceraceae</i>	<i>Acer japonicum</i> , Thunb.	Hauchihakaede		0.72	0.60			98	88		87	105	71		0.15-0.18	0.12-0.27	
752		<i>Acer palmatum</i> , Thunb.	Kaede	0.96	0.70	0.60	60		85	145		83	116	136	0.54	0.36	0.36	
753		<i>Acer pictum</i> , Thunb. var. <i>typicum</i> , Koidz.	Itayakaede	0.86	0.67	0.57	54		83	90		100	98	99	1.08	0.18		
754		<i>Acer rufrinerve</i> , S. and Z.	Urihadakaede	0.88	0.59	0.51	73		84	96		87	117	108	2.10			
755	<i>Anacardiaceae</i>	<i>Rhus vernicifera</i> , DC.	Urushi	0.88	0.51	0.44	100		118	105		136		127	0.09			
756	<i>Aquifoliaceae</i>	<i>Ilex crenata</i> , Thunb.	Inutsuge	1.04	0.72	0.63	65		74			81		75				
757		<i>Ilex macropoda</i> , Miq.	Aohada		0.66	0.57			106			108			0.12			
758	<i>Araliaceae</i>	<i>Kalopanax ricinifolius</i> , Miq.	Harigiri	0.83	0.54	0.47	75		105	105		91	99	101	84	1.08	0.42	0.36-0.42
759	<i>Betulaceae</i>	<i>Alnus firma</i> , S. and Z. var. <i>Sieboldiana</i> , Winkel.	Yashabushi		0.64	0.55			72	54		76		91		0.45		
760		<i>Alnus incana</i> , Willd. var. <i>sibirica</i> , Spach.	Yamahannoki	0.75	0.50	0.40	88		72	55		90		99	3.00	0.90	0.90	
761		<i>Alnus japonica</i> , S. and Z.	Hannoki	0.69	0.50	0.42	60		95	77		101		87	96	3.00		
762		<i>Betula carpinifolia</i> , S. and Z.	Midzume		0.77	0.66		83	85	81	98	87		108	84			
763		<i>Betula Ermani</i> , Cham. and Schl. var. <i>japonica</i> , Koidz.	Makamba	1.01	0.63	0.55	84		127	132		107		107				
764		<i>Betula japonica</i> , Sieb.	Shirakamba		0.70	0.60		75	84	77	123	88		101	110	1.05	0.36	0.18-0.42
765		<i>Betula Maximowicziana</i> , Regel.	Saihadakamba		0.68	0.58			118	72		96				0.06		
766		<i>Betula Schmidtii</i> , Regel.	Onoorekamba		0.86	0.75			120	146		122		125	108	0.03		
767		<i>Betula ulmifolia</i> , S. and Z.	Yogusominebari	0.91	0.70	0.60	52	110	107	155	116	109	90		97	0.03		
768		<i>Carpinus cordata</i> , Bl.	Sawashiba	0.93	0.71	0.57	63		110	114		100		111		0.09		
769		<i>Carpinus japonica</i> , Bl.	Kumashide	1.00	0.72	0.58	72		133	93		104		137	129		0.06	
770		<i>Ostrya italica</i> Scop. var. <i>virginiana</i> , Winkel.	Asada		0.70	0.60			89	90		109	79	110	77	0.06	0.21	0.12
771	<i>Buxaceae</i>	<i>Buxus japonica</i> , Muell. Arg.	Tsuge	1.01	0.75	0.65	55		124	70		91				0.03		
772	<i>Cornaceae</i>	<i>Cornus controversa</i> , Hemsl.	Midzuki	0.90	0.60	0.50	80		88	65		98		99	84	0.90		0.12-0.15
773	<i>Ebenaceae</i>	<i>Diospyros lotus</i> , L.	Mamegaki		0.60	0.50			99	71		85			81	0.84	0.15-0.18	
774	<i>Euphorbiaceae</i>	<i>Bischofia javanica</i> , Bl.	Akagi		0.75	0.65		70	75	88	47	57		97	127			
775	<i>Fagaceae</i>	<i>Castanea sativa</i> , Mill.	Kuri	0.98	0.60	0.52	89		81	81		91	90	96	89	3.00	0.42-0.57	0.12-0.80
776		<i>Castanopsis taiwaniana</i> , Hay.	Kurikashi		0.77	0.66		98	90	111	63	74						
777		<i>Fagus Sieboldi</i> , Endl.	Buna	1.08	0.66	0.57	90	128	108	128	100	117		100	110	0.30	0.54	0.30
778		<i>Pasania cuspidata</i> , Oerst.	Shii	1.28	0.62	0.54	137	104	103	91	108	94		92	107		0.33	0.39-0.48

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
779		<i>Pasania glabra</i> , Oerst.	Shiribukagashi		0.69	0.60			106	88		120						
780		<i>Quercus acuta</i> , Thunb.	Akagashi	1.15	0.85	0.73	58	103	92	94	82	80		96	107	0.03	0.06	0.03-0.05
781		<i>Quercus amygdalifolia</i> , Skan.	Amigashi		1.16	0.93		91	74	102	50	75		75	102		0.42	0.36
782		<i>Quercus crispula</i> , Bl.	Öhnara	1.02	0.73	0.63	62	71	75	91	89	98		85	77	0.06	0.12	
783		<i>Quercus gilva</i> , Bl.	Ichigashi	1.05	0.80	0.68	54	122	108	89	88	85		94	98	0.09	0.15-0.21	0.12-0.15
784		<i>Quercus glandulifera</i> , Bl.	Konara	1.11	0.75	0.65	71	90	89	97	97	95		87	119	0.06	0.09	0.09
785		<i>Quercus glauca</i> , Thunb.	Arakashi	1.17	0.82	0.70	67	102	117	77	77	88		100	91	0.03	0.06-0.18	0.06-0.09
786		<i>Quercus myrsinaefolia</i> , Bl.	Shirakashi	1.11	0.85	0.72	54	95	96	70	78	89		115	84	0.03	0.03-0.06	0.03-0.05
787		<i>Quercus phyllireoides</i> , A. Gr.	Ubamegashi	1.24	0.85	0.74	68								147			
788		<i>Quercus serrata</i> , Thunb.	Kunugi		0.84				70	68		95		89	110	0.03		
789		<i>Quercus stenophylla</i> , Makino.	Urajirogashi	1.08	0.83	0.70	54	139	126	134	88	103		97	113	0.03		
790	<i>Ginkgoaceae</i>	<i>Ginkgo biloba</i> , L.	Ichō	0.84	0.44	0.38	111		104	92		100		104	71		1.38-1.50	1.20-1.38
791	<i>Hamamelidaceae</i>	<i>Distylium racemosum</i> , S. and Z.	Isunoki	1.31	0.96	0.83	58		115	118		92		103	84	0.03		
792	<i>Hippocastanaceae</i>	<i>Aesculus turbinata</i> , Bl.	Tochinoki	0.70	0.60	0.50	40	113	113		105	92		113	111			
793	<i>Juglandaceae</i>	<i>Juglans mandschurica</i> , Maxim.	Manshūgurumi		0.48	0.42		117	110	143		128						
794		<i>Juglans Sieboldiana</i> , Maxim.	Onigurumi	0.90	0.54	0.47	92	107	100	132	97	113	125	111	136	1.02	0.33-0.85	0.33-0.66
795		<i>Pterocarya rhoifolia</i> , S. and Z.	Sawagurumi	0.56	0.40	0.35	60		126	69		91	104	107	138	3.00		
796	<i>Lauraceae</i>	<i>Actinodaphne lancifolia</i> , Meisn.	Kagonoki	1.03	0.71	0.63	64		77	83		77		109			0.02	0.06
797		<i>Cinnamomum camphora</i> , Ness.	Kusu	0.97	0.55	0.45	116		71	95		106	99	75	66		0.96	0.60
798		<i>Cinnamomum pedunculatum</i> , Ness.	Yabunikkei	0.89	0.55	0.46	94		70	81		86		103	90	3.00	0.84	0.72
799		<i>Machilus Thunbergii</i> , S. and Z.	Tabu	1.01	0.69	0.55	84	76	74	107	105	107	106	83	114	0.06		0.42
800	<i>Leguminosae</i>	<i>Acacia confusa</i> , Merril.	Sōshiju		0.96	0.77		60	67	69	41	60						
801		<i>Albizia Julibrissin</i> , Durraz.	Nemunoki	0.86	0.55	0.47	83		86	74		89			159			0.30
802		<i>Gleditschia horrida</i> , Makino.	Saikachi	1.03	0.74	0.64	61		95	87		92				0.09	0.09-0.15	0.09-0.12
803		<i>Maackia amurensis</i> , Rupr. and Maxim.	Inuenju	0.98	0.75	0.63	56		107	95		78	79	106	112	0.06		0.12
804	<i>Magnoliaceae</i>	<i>Magnolia hypoleuca</i> , S. and Z.	Hōnoki	0.86	0.51	0.44	84		98	116		92	110	113	113	3.00	0.27	0.24
805		<i>Magnolia Kobus</i> , DC.	Kobushi	0.75	0.60	0.50	50		86	80		107		91	95	0.06		
806	<i>Moraceae</i>	<i>Ficus retusa</i> , L. var. <i>nitida</i> , Miq.	Gajumaru	0.90	0.58	0.50	80		61	52		83						
807		<i>Morus alba</i> , L. var. <i>stylosa</i> , Bureau	Yamaguwa	0.98	0.67	0.58	69		100	85		102			116	0.06	0.12	0.06
808	<i>Myricaceae</i>	<i>Myrica rubra</i> , S. and Z.	Yamamomo	1.08	0.67	0.58	86		96	93		113		98	81	0.12		
809	<i>Oleaceae</i>	<i>Fraxinus Bungeana</i> , DC. var. <i>pubinervis</i> , Wg.	Toneriko	1.02	0.71	0.60	70		149	103		103		98	111		0.06-0.09	0.06
810		<i>Fraxinus longicuspis</i> , S. and Z.	Aotago		0.70	0.61			110	86		100		100				
811		<i>Fraxinus mandschurica</i> , Rupr.	Yachidamo	0.94	0.62	0.54	74		92	115		108	89	105	119		0.82	0.48
812		<i>Fraxinus Spaethiana</i> , Lingelsh.	Shioji	0.90	0.66	0.56	61	125	137	117	67	116		100	108	0.06		
813	<i>Pinaceae</i>	<i>Abies firma</i> , S. and Z.	Momi	0.97	0.48	0.42	131	106	105	139	126	105	98	101	122	3.00	0.63-1.44	0.30-1.17
814		<i>Abies sachalinensis</i> , Mast.	Todomatsu	0.82	0.41	0.35	134	95	96	106	118	125	106	111	98	3.00		
815		<i>Abies Veitchii</i> , Lindl.	Shirabe	0.73	0.40	0.33	121	88	100	93	118	124	97	124	94	3.00		1.44-1.80
816		<i>Chamaecyparis formosensis</i> , Matsum.	Benihi		0.37	0.32		98	97	106	65	103			94			
817		<i>Chamaecyparis obtusa</i> form. <i>formosana</i> , Hayata.	Taiwanhinoki		0.48	0.41		100	119	131	68	98			113			
818		<i>Chamaecyparis obtusa</i> , S. and Z.	Hinoki	0.98	0.46	0.40	145	132	125	115	134	123	106	110	93	3.00		1.08
819		<i>Chamaecyparis pisifera</i> , S. and Z.	Sawara	* 0.80	0.43	0.37		99	94	146		116	88					
820		<i>Cryptomeria japonica</i> , Don.	Sugi	0.89	0.40	0.34	162	125	129	111	118	141	111	102	81	3.00		0.90-1.14
821		<i>Larix dahurica</i> var. <i>Principis Rupprechtii</i> , Rehd. and Wilson.	Chōsenkaramatsu	† 0.67	0.36	0.31		121	131	75	131	107						
822		<i>Larix leptolepis</i> , Gord.	Karamatsu		0.67	0.56		82	80	81		99		68	121			
823		<i>Libocedrus macrolepis</i> , Benth.	Shōnanboku	0.95	0.58	0.50	90	101	97	99	101	109	86	115	104	0.15	0.42	
824		<i>Picea ajanensis</i> , Fisch.	Ezomatsu		0.69			69	74	76	53	76						
825		<i>Picea Glehnii</i> , Mast.	Akazomatsu	0.71	0.42	0.37	92	108	103	96	117	112	106	116	126	3.00		3.00
826		<i>Picea Hondoensis</i> , Mayr.	Tōhi		0.47	0.41		153	141	134	137	153	96	104	154	3.00		3.00
827		<i>Pinus densiflora</i> , S. and Z.	Akamatsu		0.43	0.38		100	106	112	153	119	101	103	110	3.00	1.14	3.00
828		<i>Pinus koraiensis</i> , S. and Z.	Chōsenmatsu	0.95	0.52	0.46	98	137	135	110	101	95	79	97	92	3.00	1.14	
829		<i>Pinus Thunbergii</i> , Parl.	Kuromatsu	0.91	0.51	0.45	102	60	70	65	101	66		69	56	3.00	1.14-1.20	
830		<i>Pseudotsuga japonica</i> , Shirasawa.	Togasawara	0.97	0.53	0.47	106		100	110		125		96	71	3.00	0.42-1.65	1.20
831		<i>Sciadopitys verticillata</i> , S. and Z.	Kōyamaki	0.94	0.50	0.43	119		103	127		131		116	81	3.00		3.00
832		<i>Taiwania cryptomerioides</i> , Hay.	Taiwansugi		0.50	0.45			95	122		87		108	93	3.00		
833		<i>Thuja japonica</i> , Maxim.	Nezuko		0.47	0.40		101	105	121	43	105						
834		<i>Thujopsis dolabrata</i> , S. and Z.	Hiba	0.61	0.37	0.32	91		95	86		115		112	74	3.00		3.00
835		<i>Tsuga Sieboldii</i> , Carr.	Tsuga	0.97	0.50	0.44	120	113	109	132	115	115	87	89	79	3.00	3.00	1.44
836	<i>Rosaceae</i>	<i>Micromeles alnifolia</i> , Koidz.	Adzukinashi	1.02	0.53	0.45	117	124	120	127	121	137	94	128	104	3.00	0.30-0.54	0.21-0.42
837		<i>Photinia villosa</i> , DC.	Ushikoroshi	0.80	0.60	0.50	60		84	77		97		97	74	0.06		
838		<i>Prunus donarium</i> , Sieb. subsp. <i>elegans</i> , Koidz. var. <i>glabra</i> , Koidz.	Yamazakura	1.16	0.90	0.80	46		95	71					72	0.06	0.03	0.03
839		<i>Prunus Grayana</i> , Maxim.	Uwamizuzakura	1.05	0.67	0.58	81		91	97		73	96	102	116	0.24	0.12	0.09-0.12
840		<i>Prunus spinulosa</i> , S. and Z.	Rinboku		0.56	0.31	0.27	107		119	96	107		110	86	3.00		3.00
841	<i>Rutaceae</i>	<i>Phellodendron amurense</i> , Rupr.	Kihada	0.70	0.58	0.50	40		96	139		94	116	117	111	0.41	0.48	
842	<i>Salicaceae</i>	<i>Populus balsamifera</i> , L.	Deronoki		0.64	0.48	0.42	52		104	125	113	122	102	131	3.00	0.72-0.78	0.18-0.42
843		<i>Populus tremula</i> , L. var. <i>villosa</i> , Wesm.	Yamanarashi	0.83	0.38	0.33	152		88	114		85	106	94	82	3.00		
844	<i>Scrophulariaceae</i>	<i>Paulownia tomentosa</i> , Bail.	Kiri	0.70	0.48	0.40	75	111	111	97	71	118	120	131	147	3.00		
845	<i>Simarubaceae</i>	<i>Picrasma quassioides</i> , Benn.	Nigaki		0.56	0.31	0.27	107		119	96	107		110	86	3.00		



1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
846	<i>Styracaceae</i>	<i>Styrax japonica</i> , S. and Z.	Egonoki	0.97	0.60	0.52	87		114	141		105		104	151	0.06		
847	<i>Taxaceae</i>	<i>Podocarpus Nageia</i> , R. Br.	Nagi	0.88	0.55	0.47	82		97	157		127		117	56	0.12		0.60
848		<i>Taxus cuspidata</i> , S. and Z.	Ichii	0.90	0.58	0.50	80		128	73		147	138	108	67	0.12	0.33	0.27
849		<i>Torreya nucifera</i> , S. and Z.	Kaya	1.03	0.56	0.48	115		107	96		118	118	92	111			
850	<i>Tiliaceae</i>	<i>Tilia japonica</i> , Engler.	Shinanoki		0.51	0.45			86	122		113		98	113	3.00	0.90	0.78
851	<i>Trochodendraceae</i>	<i>Cercidiphyllum japonicum</i> , S. and Z.	Katsura	0.58	0.45	0.38	53	71	75	88	90	89		103	80	0.09	1.20	1.02
852		<i>Euptelaea polyandra</i> , S. and Z.	Fusazakura	0.93	0.64	0.51	82		95	95		94		83	87	0.57	0.18-0.27	0.12-0.18
853	<i>Ulmaceae</i>	<i>Aphananthe aspera</i> , Planch.	Mukuenoki	1.02	0.68	0.58	76		93	107		100		116	125	0.45		
854		<i>Celtis sinensis</i> , Pers.	Enoki	0.94	0.60	0.52	81		77	74		79		89	97	1.26		
855		<i>Ulmus campestris</i> , Sm. var. <i>laevis</i> , Planch.	Harunire	0.94	0.62	0.54	74		81	97		70		86	131		0.42	0.36
856		<i>Ulmus campestris</i> , Sm. var. <i>major</i> , Planch.	Niganire	0.90	0.60	0.50	50		65	62		60		84	54			
857		<i>Ulmus montana</i> , Sm. var. <i>laciniata</i> , Trautv.	Ohionire	0.90	0.57	0.50	80		105	149		101		108				
858		<i>Ulmus parvifolia</i> , Jacq.	Akinire	0.94	0.61	0.53	77		87	71		73			94			
859		<i>Zelkova acuminata</i> , Planch. form. <i>Keaki</i> .	Keaki	1.06	0.70	0.60	77	112	142	127	71	117	127	109	122	0.06	0.12	0.12

\* Kiso-district in Honshū.

† Obi-district in Kyūshū.

## THE WOODS OF MEXICO, CENTRAL AND SOUTH AMERICA AND THE WEST INDIES

### SAMUEL J. RECORD

With the exception of the bulk density values recorded below, the available published data on mechanical properties of woods native to these countries are of doubtful reliability.

BULK DENSITY OF THOROUGHLY AIR-DRY SAMPLES  
Values determined in the laboratory of the Yale School of Forestry

Index No.	Family	Genus and species	Common name	Place of growth of material tested	$D_d$ g/cm <sup>3</sup>
860	<i>Acanthaceae</i>	<i>Bravaisia floribunda</i> , DC.	Sancho-araña	Colombia	0.53
861	<i>Amygdalaceae</i>	<i>Licania hypoleuca</i> , Benth.	Chozo	Guatemala	1.03
862		<i>Moquilea tomentosa</i> , Benth.	Oity	Brazil	0.98
863	<i>Anacardiaceae</i>	<i>Anacardium rhinocarpus</i> , DC.	Espavé	Panama	0.54
864		<i>Astronium balansae</i> , Engl.	Urunday	Argentina	1.00-1.30
865		<i>Astronium fraxinifolium</i> , Schott.	Gonçalo Alves	Brazil	0.85-1.00
866		<i>Loxopterygium sagotii</i> , Hook. f.	Hoobooballi	British Guiana	0.60-0.70
867		<i>Tapirira guianensis</i> , Aubl.	Duka	British Guiana	0.54
868		<i>Schinopsis lorentzii</i> , Engl.	Quebracho colorado	Argentina	1.15-1.35
869	<i>Anonaceae</i>	<i>Oxandra lanceolata</i> , (Sw.) Baill.	Yaya, lancewood	Cuba	0.98
870	<i>Apocynaceae</i>	<i>Aspidosperma polyneuron</i> , Muell. Arg.	Peroba rosa	Brazil	0.70
871		<i>Aspidosperma quebracho-blanco</i> , Schl.	Quebracho blanco	Argentina	0.90-1.00
872		<i>Aspidosperma tomentosum</i> , Mart.	Guatambú	Brazil	0.77
873		<i>Aspidosperma Vargasii</i> , C. DC.	Amarillo	Venezuela	0.90-0.95
874	<i>Aquifoliaceae</i>	<i>Ilex</i> sp.	Kakatará-balli	British Guiana	0.80
875	<i>Araliaceae</i>	<i>Didymopanax morototoni</i> , (Aubl.) D. and P.	Yagrumé	Tropical America	0.45
876	<i>Betulaceae</i>	<i>Alnus</i> sp.	Jaul	Costa Rica	0.47
877	<i>Bignoniaceae</i>	<i>Crescentia cujete</i> , L.	Cujete	Tropical America	0.60
878		<i>Jacaranda copaia</i> , (Aubl.) D. Don	Fotui	British Guiana	0.40-0.47
879		<i>Tabebuia donnell-smithii</i> , Rose	Prima vera	Mexico	0.45-0.50
880		<i>Tecoma</i> , spp.	Lapacho, guayacan	Tropical America	0.95-1.25
881		<i>Tecoma pentaphylla</i> , Juss.	Roble	Tropical America	0.60-0.68
882		<i>Tecoma peroba</i> , Record	Ipé peroba	Brazil	0.70-0.83
883	<i>Bombacaceae</i>	<i>Bombacopsis</i> spp.	Saqui-saqui	Venezuela	0.41-0.59
884		<i>Bombax</i> spp.	Imbirussú	Brazil	0.24-0.40
885		<i>Cavanillesia platanifolia</i> , H. B. K.	Bongo	Panama	0.10
886		<i>Ceiba pentandra</i> , (L.) Gaertn.	Ceibo	Tropical America	0.40-0.45
887		<i>Chorisia speciosa</i> , St. Hil.	Samohú	Argentina	0.35-0.45
888		<i>Ochroma</i> spp.	Balsa	Tropical America	0.12-0.20
889		<i>Quararibea</i> sp.	Veroity	Brazil	0.72
890	<i>Boraginaceae</i>	<i>Auxemma gardneriana</i> , Miers	Páo branco	Brazil	0.70
891		<i>Cordia gerascanthoides</i> , H. B. K.	Boscote	Mexico	0.97
892		<i>Cordia gerascanthus</i> , L.	Laurel	Central America	0.61
893		<i>Cordia goeldiana</i> , Huber	Frei-jo	Brazil	0.60
894		<i>Patagonula americana</i> , L.	Guayabí	Argentina	0.85-0.90
895	<i>Burseraceae</i>	<i>Bursera gummiifera</i> , (L.) Sargent	West Indian birch	West Indies	0.35-0.40

Index No.	Family	Genus and species	Common name	Place of growth of material tested	$D_d$ g/cm <sup>3</sup>
896	Canellaceae	<i>Canella winterana</i> , Gaertn.	Canela	West Indies	1.10
897	Celastraceae	<i>Goupia glabra</i> , Aubl.	Cupiúba	Brazil	0.82-0.88
898		<i>Maytenus obtusifolia</i> , Mart.	Carne d'anta	Brazil	0.82
899	Combretaceae	<i>Terminalia</i> sp.	Naranjo	Guatemala	0.65-0.75
900		<i>Terminalia januarensis</i> , DC.	Araça	Brazil	0.77
901	Cunoniaceae	<i>Weinmannia trichosperma</i> , Cav.	Tenio	Chile	0.59
902	Dilleniaceae	<i>Curatella americana</i> , L.	Chaparro	Tropical America	0.77
903	Eucryphiaceae	<i>Eucryphia cordifolia</i> , Cav.	Ulmo	Chile	0.63
904	Euphorbiaceae	<i>Gymnanthes lucida</i> , Sw.	Aité	Cuba	1.00-1.20
905		<i>Hieronymia alchorneoides</i> , Fr. Allem.	Urucurana	Brazil	0.72
906		<i>Hippomane mancinella</i> , L.	Manzanillo	West Indies	0.68
907		<i>Hura crepitans</i> , L.	Javillo, possum wood	Tropical America	0.36-0.44
908	Flacourtiaceae	<i>Casearia praecox</i> , Gris.	Zapatero, W. Ind. boxwood	Venezuela	0.80-0.90
909		<i>Homalium</i> sp.	Angelino	Venezuela	0.75-0.85
910	Guttiferae	<i>Calophyllum calaba</i> , Jacq.	Santa María	Central America	0.68-0.74
911		<i>Mammea americana</i> , L.	Mamey	West Indies	0.90
912		<i>Platonia insignis</i> , Mart.	Pacouri	French Guiana	0.86
913		<i>Symphonia globulifera</i> , L. f.	Waikey, chewstick	British Honduras	0.65-0.70
914	Humiriaceae	<i>Humiria floribunda</i> , Mart.	Bastard bullet wood	British Guiana	0.85-0.92
915	Juglandaceae	<i>Juglans australis</i> , Gris.	Nogal	Argentina	0.56
916	Lauraceae	<i>Aniba panurensis</i> , Mez	Bois de rose	French Guiana	0.60-0.68
917		<i>Nectandra</i> sp.	Determa	British Guiana	0.65-0.70
918		<i>Nectandra</i> sp.	Embuia	Brazil	0.70-0.76
919		<i>Nectandra</i> sp.	Waibaima	British Guiana	1.15
920		<i>Nectandra rodioei</i> , Schomb.	Greenheart	British Guiana	1.06-1.23
921		<i>Persea lingue</i> , Nees	Lingue	Chile	0.55
922		<i>Phoebe ambigens</i> , Blake	Guambo	Honduras	0.50
923		<i>Phoebe porphyria</i> , (Gris.) Mez	Laurel negro	Argentina	0.50-0.80
924		<i>Silvia navalium</i> , Fr. Allem.	Tapinhoan	Brazil	0.86-1.00
925	Lecythydaceae	<i>Cariniana legalis</i> , (Mart.) Kuntze	Jequitibá	Brazil	0.50-0.70
926		<i>Cariniana pyriformis</i> , Miers	Albarco, Colombian mahogany	Colombia	0.65-0.70
927		<i>Chytroma jarana</i> , Huber	Jaraná	Brazil	0.98
928		<i>Eschweilera corrugata</i> , Miers	Manbarklak	Dutch Guiana	1.21
929		<i>Lccythis ollaria</i> , L.	Sapucaia	Brazil	0.95
930	Leguminosae	<i>Andira vermifuga</i> , Mart.	Angelim amargoso	Brazil	0.65
931		<i>Apuleia praecox</i> , Mart.	Iberá-peré	Argentina	0.80-0.95
932		<i>Bowdichia</i> sp.	Sucupira	Brazil	1.00
933		<i>Brya ebenus</i> , DC.	Granadillo	Cuba	1.20
934		<i>Caesalpinia echinata</i> , Lam.	Páo brasil, Pernambuco wood	Brazil	0.98-1.24
935		<i>Caesalpinia granadillo</i> , Pittier	Ebano, coffee wood, partridge	Venezuela	1.10-1.20
936		<i>Caesalpinia melanocarpa</i> , Gris.	Guayacan negro	Argentina	1.10-1.30
937		<i>Centrolobium</i> spp.	Araribá	Brazil	0.65-0.90
938		<i>Copaifera officinalis</i> , (L.) Willd.	Copaiba	Colombia	0.70
939		<i>Dalbergia</i> sp.	Honduras rosewood	British Honduras	0.93-1.08
940		<i>Dalbergia nigra</i> , Fr. Allem.	Jacarandá, Brazilian rosewood	Brazil	0.85
941		<i>Dalbergia retusa</i> , Hemsl.	Cocobolo	Central America	0.99-1.22
942		<i>Dialium divaricatum</i> , Vahl.	Jutahy peba	Brazil	0.90
943		<i>Dicorynia paraensis</i> , Benth.	Angélique	French Guiana	0.75-0.90
944		<i>Dimorphandra mora</i> , B. and H.	Mora	British Guiana	0.97-1.00
945		<i>Diploptropis</i> sp.	Zwarte kabbes	Dutch Guiana	1.15
946		<i>Dipteryx odorata</i> , Willd.	Tonca bean	British Guiana	1.20
947		<i>Enterolobium cyclocarpum</i> , (Jacq.) Gris.	Guanacaste	Central America	0.35-0.60
948		<i>Eperua falcata</i> , Aubl.	Wallaba	British Guiana	0.90
949		<i>Erythrina crista-galli</i> , L.	Ceibo	Argentina	0.25
950		<i>Eysenhardtia polystachia</i> , (Ort.) Sarg.	Palo dulce	Mexico	0.87
951		<i>Gleditschia amorphoides</i> , (Gris.) Taub.	Espina corona	Argentina	0.86-0.95
952		<i>Haematoxylon campechianum</i> , L.	Logwood	British Honduras	1.00
953		<i>Holocalyx balansae</i> , Mich.	Alecrin	Argentina	1.00
954		<i>Hymenaea courbaril</i> , L.	Courbaril, algarroba, locust	Tropical America	0.80-1.05
955		<i>Lysiloma sabicu</i> , Benth.	Sabicú	Cuba	0.77
956		<i>Melanoxyton brauna</i> , Schott.	Braúna	Brazil	1.00
957		<i>Myrocarpus frondosus</i> , Fr. Allem.	Cabreúva	Brazil	0.87-0.97
958		<i>Myroxyton toluiferum</i> , H. B. K.	Oleo vermelho	Brazil	1.00



Index No.	Family	Genus and species	Common name	Place of growth of material tested	$D_a$ g/cm <sup>3</sup>
959		<i>Peltogyne paniculata</i> , Benth.	Purpleheart	British Guiana	1.00
960		<i>Peltophorum adnatum</i> , Gris.	Sabicú moruro	Cuba	1.02
961		<i>Peltophorum vogelianum</i> , Benth.	Caña fistola	Argentina	0.75-1.04
962		<i>Piptadenia</i> sp.	Curupay	Argentina	1.03
963		<i>Piptadenia rigida</i> , Benth.	Angico	Argentina	0.95
964		<i>Pithecolobium arboreum</i> , (L.) Urb.	Moruro	Cuba	0.74
965		<i>Pithecolobium racemiflorum</i> , Ducke	Bois serpent	French Guiana	1.15
966		<i>Pithecolobium vinhatico</i> , Record	Vinhatico de espinho	Brazil	0.60
967		<i>Plathymenia reticulata</i> , Benth.	Vinhatico castanho	Brazil	0.56-0.65
968		<i>Platycamus regnellii</i> , Benth.	Pereira	Brazil	0.75
969		<i>Platymiscium polystachyum</i> , Benth.	Roble colorado	Venezuela	1.00
970		<i>Pterogyne nitens</i> , Tul.	Ibiráro	Argentina	0.76-1.09
971		<i>Swartzia tomentosa</i> , DC.	Wamara	British Guiana	1.05-1.28
972		<i>Sweetia panamensis</i> , Benth.	Billy Webb	British Honduras	1.00
973		<i>Tipuana speciosa</i> , Benth.	Tipa	Argentina	0.65
974		<i>Torresia cearensis</i> , Fr. Allem.	Umburana	Brazil	0.60
975		<i>Vouacapoua americana</i> , Aubl.	Acapú	Brazil	0.87-0.92
976		<i>Zollernia paraensis</i> , Huber	Páo santo	Brazil	1.30-1.33
977	Magnoliaceae	<i>Drimys winteri</i> , Forst.	Canelo	Chile	0.50
978	Malpighiaceae	<i>Byrsonima crassifolia</i> , H. B. K.	Nance	Mex., Centr. Amer.	0.70
979	Malvaceae	<i>Hibiscus elatus</i> , Sw.	Majagua	Cuba	0.65
980	Melastomaceae	<i>Mouriria pseudo-geminata</i> , Pittier	Pauji	Venezuela	0.82
981	Meliaceae	<i>Cabralea</i> spp.	Cancharana	Argentina	0.65
982		<i>Carapa guianensis</i> , Aubl.	Crabwood	British Guiana	0.60-0.75
983		<i>Cedrela</i> spp.	Cedro, cedar	Tropical America	0.37-0.70
984		<i>Guarea trichilioides</i> , L.	Muskwood	Jamaica	0.50-0.55
985		<i>Swietenia</i> spp.	Caoba, mahogany	Tropical America	0.45-0.85
986		<i>Trichilia alta</i> , Blake.	Pimenteira	Brazil	0.72
987	Monimiaceae	<i>Laurelia aromatica</i> , Juss.	Laurel	Chile	0.53
988	Moraceae	<i>Bagassa guianensis</i> , Aubl.	Tatajuba	Brazil	0.80
989		<i>Brosimopsis diandre</i> , Blake	Leiteira	Brazil	0.75
990		<i>Brosimum columbianum</i> , Blake	Guayamero	Colombia	0.81
991		<i>Brosimum paraense</i> , Huber	Satiné	French Guiana	0.98-1.05
992		<i>Cecropia adenopus</i> , Mart.	Ambay	Argentina	0.44
993		<i>Chlorophora tinctoria</i> , Gaud.	Mora, fustic	Tropical America	0.93-0.99
994		<i>Clarisia racemosa</i> , R. and P.	Oitiçica	Brazil	0.50-0.60
995		<i>Perebea</i> sp.	Kapiteinhout	Dutch Guiana	0.68
996		<i>Piratinera guianensis</i> , Aubl.	Letterhout, letterwood	Dutch Guiana	1.20-1.35
997	Myristicaceae	<i>Virola bicuhyba</i> , Warb.	Bicuiba	Brazil	0.63-0.72
998		<i>Virola sebifera</i> , Aubl.	Yayamadou	French Guiana	0.60
999	Myrsinaceae	<i>Rapanea laetevirens</i> , Mez.	Canelon	Argentina	0.55
1000	Olacaceae	<i>Minuartia guianensis</i> , Aubl.	Acaricuára	Brazil	0.98
1001	Phytolaccaceae	<i>Gallesia scorododendron</i> , Casar.	Páo d'alho	Brazil	0.58
1002	Pinaceae	<i>Araucaria brasiliana</i> , Lamb.	Pinheiro do Paraná	Brazil	0.50-0.60
1003	Polygonaceae	<i>Coccoloba uvifera</i> , L.	Uvero	Tropical America	0.98-1.10
1004		<i>Ruprechtia</i> sp.	Virarú	Argentina	0.66-0.76
1005	Protaceae	<i>Roupala brasiliensis</i> , Kl.	Páo concha	Brazil	0.80-1.00
1006	Rubiaceae	<i>Calderonia salvadorensis</i> , Standl.	Brasil	Salvador	0.60
1007		<i>Calycophyllum candidissimum</i> , (Vahl.) DC.	Dágame, salamo, degame	W. I., Centr. Amer.	0.80
1008		<i>Calycophyllum multiflorum</i> , Gris.	Palo blanco	Argentina	0.92-1.03
1009		<i>Genipa americana</i> , L.	Jagua	Tropical America	0.73-0.84
1010		<i>Sickingia</i> sp.	Arariba	Brazil	0.88
1011	Rutaceae	<i>Amyris balsamifera</i> , L.	Amyris	Venezuela	0.99-1.10
1012		<i>Balfourodendron riedelianum</i> , Engl.	Guatambú	Argentina	0.75
1013		<i>Esenbeckia leiocarpa</i> , Engl.	Guarantán	Brazil	0.97-1.10
1014		<i>Euxylophora paraensis</i> , Huber	Páo amarello	Brazil	0.81
1015		<i>Zanthoxylum flavum</i> , Vahl.	West Indian satinwood	West Indies	0.90
1016	Salicaceae	<i>Salix humboldtiana</i> , Willd.	Sauce colorado	Argentina	0.44
1017	Sapotaceae	<i>Achras zapota</i> , L.	Nispero	Central America	1.09
1018		<i>Labourdonnaisia albescens</i> , Benth.	Almique	Cuba	0.97
1019		<i>Lucuma procera</i> , Mart.	Mucuri	Brazil	0.90
1020		<i>Mimusops</i> sp.	Massaranduba	Brazil	0.85-1.10
1021		<i>Mimusops globosa</i> , Gaertn.	Bullet wood	British Guiana	0.90-1.25

Index No.	Family	Genus and species	Common name	Place of growth of material tested	$D_a$ g/cm <sup>3</sup>
1022	Simarubaceae	<i>Pradosia latescens</i> , (Vell.) Radlk.	Buranhem	Brazil	0.94
1023		<i>Sideroxylon mastichodendron</i> , Jacq.	Jocuma	Cuba	0.95-1.10
1024		<i>Quassia amara</i> , L.	Quassia	Surinam	0.50
1025	Sterculiaceae	<i>Simaruba amara</i> , Aubl.	Marupá	Brazil	0.40-0.50
1026		<i>Sterculia</i> sp.	Imbira quiaba	Brazil	0.25
1027		<i>Caryocar villosum</i> , Pers.	Piquiá	Brazil	0.81
1028	Tiliaceae	<i>Guazuma ulmifolia</i> , Lam.	Guacima	Tropical America	0.55
1029	Ulmaceae	<i>Luehea divaricata</i> , Mart.	Açoita-cavallo	Brazil	0.60
1030		<i>Celtis tala</i> , Gill.	Tala	Argentina	0.60-0.85
1031		<i>Phyllostylon brasiliensis</i> , Cap.	Baitoa, San Domingan boxwood	Dominican Repub.	0.95
1032	Verbenaceae	<i>Avicennia nitida</i> , Jacq.	Mangle prieto	Tropical America	0.95-1.10
1033		<i>Petitita domingensis</i> , Jacq.	Capá	West Indies	0.95
1034		<i>Vitex longeracemosa</i> , Pittier	Jocote de mico	Guatemala	0.70
1035	Vochysiaceae	<i>Qualea rosea</i> , Aubl.	Cèdre gris	French Guiana	0.65
1036		<i>Vochysia guatemalensis</i> , J. D. Smith	San Juan	Guatemala	0.42
1037		<i>Bulnesia arborea</i> , Engl.	Vera	Venezuela	1.10-1.25
1038	Zygophyllaceae	<i>Guaiacum officinale</i> , L.	Guayacan, lignum-vitae	West Indies	1.10-1.40

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### DENSITY ARRANGEMENT

In the arrangement below, the lightest and heaviest woods are listed in the order (descending) of their bulk-densities in the air-dried condition. The bold-face numbers represent intervals on the density scale. The other numbers are the index numbers of the woods arranged in descending order of their densities. Bulk density = weight of air-dry piece divided by its bulk volume.

### ARRANGEMENT PAR DENSITÉ

Dans l'arrangement ci-dessous les bois les plus légers et les plus lourds sont indiqués dans l'ordre (descendant) de leur densité apparente dans les conditions de séchage à l'air. Les nombres en caractères gras représentent les intervalles de l'échelle des densités. Les autres nombres sont les nombres index des bois disposés dans l'ordre descendant de leurs densités. Densité apparente = poids de la pièce séchée à l'air divisé par son volume apparent.

### ANORDNUNG DER DICHTEN

In der Anordnung unten sind die leichtesten und schwersten Hölzer in absteigender Reihe ihrer Dichten im Luft trockenen Zustande angegeben. Die hervorgehobenen Zahlen bezeichnen die Intervalle an der Dichteskala. Die anderen Zahlen sind die Indexnummern der angegebenen Hölzer in absteigender Reihe ihrer Dichten. Raumgewicht = Gewicht des Luft trockenen Stückes dividiert durch sein Volumen.

### ORDINE SECONDO LE DENSITÀ

Nell'elenco che segue, i legni più leggeri e i più pesanti sono indicati nell'ordine decrescente delle loro densità nello stato

di essiccamento all'aria. I numeri marcati in nero rappresentano gli intervalli nella scala delle densità. Gli altri numeri sono i numeri indice dei legni disposti in ordine decrescente delle loro densità. Densità apparente = peso del pezzo seccato all'aria diviso per il suo volume.

**1.40:** 1038, 996, 868, 976, 412, 936, 864, 136, 971, 522. **1.25:** 1037, 1021, 880, 512, 934, 920, 941, 928, 665, 552, 420. **1.20:** 946, 935, 933, 904, 523, 513, 501, 549, 731, 565, 554, 497. **1.15:** 965, 945, 919, 414, 638, 482, 555, 415, 540, 525, 587. **1.12:** 494, 207, 493, 536, 524, 1032, 1023, 1020, 1013, 1011, 1003, 896, 409. **1.09:** 1017, 970, 551, 537, 553, 939, 138, 498, 664, 570. **1.066:** 502, 234, 651, 530, 507, 991, 954, 571, 153, 583, 475. **1.04:** 961, 442, 1008, 962, 861, 228, 644, 477, 483. **1.02:** 960, 541, 491, 387, 484, 584, 509, 654. **1.00:** 1005, 972, 969, 959, 958, 956, 953, 952, 944, 932, 924, 871, 865, 357.

**0.41:** 883, 814, 466, 88, 55, 123, 272, 115, 271. **0.40:** 1025, 886, 878, 820, 815, 785, 218, 148, 154, 247. **0.38:** 842, 720, 321, 102, 983, 833, 816, 130, 253, 209, 91, 96. **0.36:** 907, 820, 213, 144, 947, 895, 887, 819, 721, 201, 129. **0.344:** 18, 467, 454, 844, 711, 702, 463. **0.25:** 1026, 949, 884. **0.189:** 674. **0.12:** 888. **0.10:** 885.

### ARTIFICIAL LUMBERS

The data given below are intended to illustrate the order of magnitude of some of the properties found for samples of certain artificial materials manufactured in board form for special uses. Since the properties of such materials vary with the method of manufacture, and as such methods are constantly being improved, the actual characteristics of the manufactured product at a given time can be obtained only from the manufacturer.

Common or trade name	Composition and structure	Bulk density, g/cm <sup>3</sup>	Strength kg/cm <sup>2</sup> Tr. = tensile Cr. = crushing	Approximate thermal conductivity $k = \frac{\text{g-cal}}{10^{-4} \text{ cm}^2 \text{ sec}^{-1} (^\circ\text{C})}$ cf. p. 312 (4)
<b>A</b>				
Asbestos mill board.....	Asbestos + binder	1.0		29
Asbestos wood...	Asbestos + cement	2.0	1050 Cr. (3) 246 Tr.	93
Asphalt roofing..	Felt saturated with asphalt	0.9		24
Celotex*.....	Felted bagasse fibers	0.19 to 0.24	2.25 Tr. 26.2 Ten. (2)	10
Cork board.....	Cork, no binder	0.13		10
Cork board.....	Cork + bituminous binder	0.25		12
Insulite.....	Pressed wood pulp	0.19	1.62 Tr. 11.7 Ten. (2)	10 12
Lith board.....	Mineral wool, vegetable fibers + binder	0.2		
Sheet rock or plaster board	Gypsum + wood shavings		2.04 Tr. 12.3 Ten. (2)	
Wall board (gypsum).....	Gypsum			80
Wall board.....	Stiff paper	0.7	13 Ten. (1)	17
Thermolath†....	Vegetable fibers + waterproofing binder		11.9 Ten. (5) 1.14 Tr.	13 (5)

\* Water absorptivity on 48 hr immersion = 10 vol. %.

† Water absorptivity on 48 hr immersion = 41 vol. %.

### LITERATURE

(For a key to the periodicals see end of volume)

(1) Bird and Son, O. (2) Celotex Company, *Celotex*. (3) Johns-Manville Co., *Asbestos Wood*. (4) Van Dusen, 385, 26: 625; 20. (5) Waldorf Paper Products Co., O.



## BUILDING STONES

D. W. KESSLER

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## CONVERSION FACTORS

1 kg cm <sup>-2</sup>	= 14.22 lb. in. <sup>-2</sup> = 1.024 ton* ft. <sup>-2</sup>
1 dyne cm <sup>-2</sup>	= 1.020 × 10 <sup>-5</sup> kg cm <sup>-2</sup> = 1.450 × 10 <sup>-5</sup> lb. in. <sup>-2</sup> = 1.044 × 10 <sup>-6</sup> ton* ft. <sup>-2</sup>
1 kg <sup>-1</sup> cm <sup>2</sup>	= 1.020 × 10 <sup>6</sup> dyne <sup>-1</sup> cm <sup>2</sup> = 0.0703 lb. <sup>-1</sup> in. <sup>2</sup> = 1.033 atm <sup>-1</sup>
1 g cm <sup>-3</sup>	= 1000 kg m <sup>-3</sup> = 62.4 lb. ft. <sup>-3</sup> = 0.843 ton* yd. <sup>-3</sup>
1 joule cm <sup>-2</sup> sec <sup>-1</sup> (°C, cm <sup>-1</sup> ) <sup>-1</sup>	= 0.239 g-cal cm <sup>-2</sup> sec <sup>-1</sup> (°C, cm <sup>-1</sup> ) <sup>-1</sup> = 9.48 × 10 <sup>-4</sup> BTU ft. <sup>-2</sup> sec <sup>-1</sup> (°F, in. <sup>-1</sup> ) <sup>-1</sup>

per deg C = 0.556 per deg F.

\* 1 ton = 2000 lb.

## COMPRESSIVE STRENGTH

kg cm<sup>-2</sup> × 10<sup>-3</sup>

Example: For basalt from Limburg, 3200 kg per sq. cm (4).

## Basalt, Av. Range—2.0 to 3.5

Near Linz a. R.....	4.7	(6)
Limburg, Nassau.....	3.2	(4)
Ortenberg, Hesse.....	2.7	(4)
Lauterbach, Hesse.....	2.0	(4)

## Phonolite

Rothweil, Baden.....	3.4	(12)
Aschaffenburg, L. Franconia.....	3.0	(4)

## Porphyry, Av. Range—2.0 to 3.0

Quartz, Beutengrund, Silesia.....	3.2	(12)
Quartz, Reinsdorf, Silesia.....	2.2	(12)
Alpirsbach, Black Forest.....	2.0	(4)

## Quartzite, Av. Range—1.0 to 2.0

Kugelberg, Alsace.....	3.2	(4)
Sierk near Metz.....	2.9	(4)
Pipestone, Minn.....	2.0	(45)
White Haven, Pa.....	1.1	(21)

## Felsite

Rohrschweger, Alsace.....	2.9	(4)
Kerzheim, Alsace.....	2.0	(4)

## Diabase

Ochenkopf, Bavaria.....	2.7	(4)
Hasselfelde, Harz Mts .....	2.1	(12)
Taylor's Falls, Minn.....	1.8	(13)

## Diorite, Av. Range—1.0 to 2.5

Freiburg, Baden.....	2.6	(4)
Aschaffenburg, L. Franconia.....	2.4	(4)
Boulder Canyon, Ariz.....	2.0	(21)
Quartz mica, Monson, Mass .....	1.1	(23)

## Aplite

Hingham, Mass.....	2.5	(41)
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## Syenite, Av. Range—1.0 to 2.0

Fine grained, East St. Cloud, Minn.....	2.0	(13)
Porphyry, Pulaski Co., Ark.....	2.0	(34)
Red, Beaver Bay, Minn.....	1.9	(13)
Gray quartzose, East St. Cloud, Minn.....	1.9	(13)
Coarse, Watab, Minn.....	1.8	(13)
Fine grained, Sauk Rapids, Minn.....	1.5	(13)
Cape Ann, Mass.....	1.1	(13)
Weinheim, Baden.....	1.0	(4)

## Serpentine, Av. Range—0.9 to 2.0

Hollysprings, Ga.....	2.0	(21)
Auburn, Calif.....	1.8	(38)
Roxbury, Vt.....	1.7	(21)
Einseidel, Bohemia.....	1.4	(15)
Zoblitz, Saxony.....	0.8	(16)

## Granite, Av. Range—1.0 to 2.8

Quartz-monzonite, Westerly, R. I.....	2.0	(41)
Muscovite, Stone Mountain, Ga.....	1.9	(32)
Hornblende, Mosquito Mt., Maine.....	1.6	(46)
Gneiss, Branford, Conn.....	1.6	(41)
Biotite, Milford, Mass.....	1.6	(41)
Biotite gneiss, Port Deposit, Md.....	1.6	(21)
Riebeckite-aegirite, Quincy, Mass.....	1.5	(20)
Hornblende, Rockport, Maine.....	1.4	(41)

**Granite.**—(Continued)

Coarse biotite, Stony Creek, Conn.....	1.1	(13)
Gneiss, Monson, Mass.....	1.1	(41)
Biotite, Aberdeen, Scotland.....	0.8	(13)

**Gabbro**

Rice Pt., Duluth, Minn.....	1.9	(13)
Randaual, Hanover.....	1.0	(4)

**Lava**

Niedermendig, Rhine.....	1.9	(6)
Fremont Co., Colo.....	0.7	(18)

**Marble, Av. Range—0.8 to 1.5**

Hematitic dolomite, Swanton, Vt.....	1.9	(21)
Coarse dolomite, Pleasantville, N. Y.....	1.6	(13)
Carbonaceous, Isle La Motte, Vt.....	1.5	(21)
Dolomite, South Dover, N. Y.....	1.4	(21)
Dolomite, Lee, Mass.....	1.4	(21)
Pink fossiliferous, Knoxville, Tenn.....	1.2	(21)
Saccharoidal calcite, Carrara, Italy.....	1.1	(15)
Saccharoidal calcite, Plattsburg, N. Y.....	1.0	(21)
Magnesian, Gouverneur, N. Y.....	1.0	(21)
Dolomite, Beaverdam, Md.....	0.9	(21)
Graphitic dolomite, Florence, Vt.....	0.9	(21)
Carbonaceous, Glens Falls, N. Y.....	0.8	(13)
Coarse calcite, Ball Ground, Ga.....	0.8	(21)
Saccharoidal calcite, Rutland, Vt.....	0.7	(21)
Actinolitic calcite, South Dorset, Vt.....	0.6	(21)

**Dolomite, Av. Range—0.8 to 1.5**

Compact, Lemont, Ill.....	1.9	(13)
Compact, Red Wing, Minn.....	1.6	(13)
Arenaceous, Kasota, Minn.....	0.9	(21)
Bituminous, Marblehead, Ohio.....	.8	(21)
Pitted, Jefferson City, Mo.....	.8	(21)
Vesicular, Stone City, Iowa.....	.4	(3)

**Essexite**

Mt. Johnson, Quebec.....	1.8	(1)
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**Granodiorite**

Rocklin, Calif.....	1.5	(43)
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**Labradorite**

Beaver Bay, Minn.....	1.5	(13)
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**Sandstone, Av. Range—0.5 to 1.5**

Quartzitic, Potsdam, N. Y.....	1.5	(21)
Argillaceous, Warsaw, N. Y.....	1.4	(41)
Calcareous, Horst, Schleswig-Holstein.....	1.2	(12)
Calcareous, Craigleith, Scotland.....	0.9	(13)
Triassic, Hummelstown, Pa.....	.8	(21)
Triassic, Bellville, N. J.....	.8	(13)
Triassic, Portland, Conn.....	.7	(21)
Triassic, East Long Meadow, Mass.....	.7	(21)
Calcareous, Dorchester, N. B.....	.7	(13)
Feldspathic, Vitzberg, Thuringia.....	.6	(12)
Calcareous, Warrensburg, Mo.....	.4	(8)
Feldspathic, Aquia Creek, Va.....	.4	(21)
Ferruginous, Chitwood, Ore.....	.4	(41)

**Limestone, Av. Range—0.4 to 1.4**

Argillaceous, St. Paul, Minn.....	1.4	(13)
Compact, Lias, France.....	1.4	(36)
Jurassic, Chatillon, France.....	1.4	(36)

**Limestone.**—(Continued)

Aluminous, Minneapolis, Minn.....	1.2	(13)
Compact, earthy, Cassville, Mo.....	0.9	(21)
Fine-grained oolite, Marshalltown, Iowa.....	.9	(3)
Vesicular, Mantorville, Minn.....	.7	(13)
Magnesian, Andalusia, Ill.....	.4	(35)
Oolitic, Bedford, Ind.....	.4	(21)
Jurassic, Isle of Portland.....	.3	(33)
Oolitic, Caen, Normandy.....	.25	(13)
Oolitic, Bath, England.....	.09	(29)

**Conglomerate**

Wilkesbarre, Pa.....	1.3	(18)
Königssee, Thuringia.....	1.2	(12)

**Breccia (Volcanic)**

Boulder Canyon, Ariz.....	1.0	(21)
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**Tufa**

Lilliwaup, Wash.....	0.8	(31)
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**Slate**

Pen Argyl, Pa.....	0.7	(11)
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**Trachyte**

Köln, Rhine.....	0.7	(6)
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**Steatite**

Arrington, Va.....	0.6	(21)
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**Tuff**

Oregon.....	0.2	(21)
Grafenberg, Bavaria.....	0.1	(4)

**SHEARING STRENGTH**

The shearing values given in this table were determined by three types of apparatus, one of which appears to give results which are too low, due to the fact that bending stresses are produced. The values determined by authority No. 41 are probably low for this reason.

kg cm<sup>-2</sup>

**Marble, Av. Range—100 to 300**

Hematitic dolomite, Swanton, Vt.....	450	(21)
Dolomitic, Lee, Mass.....	320	(21)
Impure calcite, Carthage, Mo.....	310	(21)
Graphitic calcite, Albertson, Vt.....	260	(21)
Pink fossiliferous, Knoxville, Tenn.....	250	(21)
Karstmarmer, Nabresina, Istria.....	110	(15)
Dolomitic, Tuckahoe, N. Y.....	105	(41)
Siliceous, Neubeuern, Bavaria.....	100	(4)
Saccharoidal calcite, Carrara, Italy.....	90	(15)
Fine-grained, Laas, Tyrol.....	60	(15)

**Serpentine**

Weisen, Tyrol.....	340	(15)
Hollysprings, Ga.....	320	(21)
Einsiedel, Bohemia.....	180	(15)

**Granite, Av. Range—150 to 300**

Muscovite, Stone Mountain, Ga.....	300	(21)
Biotite, Millbridge, Maine.....	200	(18)
Biotite, Milford, Mass.....	180	(41)
Hornblende, Rockport, Mass.....	170	(41)
Hornblende, Cape Ann, Mass.....	170	(22)
Muscovite-biotite, Troy, N. H.....	160	(41)
Fine-grained biotite, Schwarzwasser, Poland.....	140	(15)
Fine-grained biotite, Mauthausen, Austria.....	140	(4)
Biotite, Hauzenberg, Bavaria.....	130	(4)
Biotite, Baveno, Italy.....	90	(15)



## Steatite

Arrington, Va.....	280	(21)
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## Slate

Calcareous mica, Pen Argyl, Pa.....	250	(21)
Siliceous mica, Monson, Maine.....	150	(27)

## Limestone, Av. Range—100 to 200

Earthy dolomite, Quincy, Ill.....	210	(21)
Aluminous dolomite, Mantorville, Minn.....	200	(21)
Gray oolitic, Bedford, Ind.....	170	(10)
Buff oolitic, Bedford, Ind.....	150	(10)
Flinty, Buffalo, N. Y.....	150	(41)
Oolitic, Rockwood, Ala.....	150	(21)
Pure white oolitic, Kehlheim, Bavaria.....	30	(4)

## Sandstone, Av. Range—50 to 150

Triassic, East Longmeadow, Mass.....	190	(21)
Fine-grained variegated, Murgtal, Baden.....	40	(4)
Argillaceous, Hochberg, Bavaria.....	30	(4)
Glauconitic, Ihrlerstein, Bavaria.....	20	(4)

## TRANSVERSE STRENGTH

Modulus of Rupture  
kg cm<sup>-2</sup>

## Serpentine, Av. Range—100 to 350

Weisen, Tyrol.....	780	(15)
Hollysprings, Ga.....	340	(21)
Roxbury, Vt.....	310	(21)
Einsiedel, Bohemia.....	160	(15)
Auburn, Calif.....	90	(38)

## Quartzite

White Haven, Pa.....	330	(21)
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## Marble, Av. Range—100 to 200

Hematitic dolomite, Swanton, Vt.....	300	(21)
Carbonaceous, Isle LaMotte, Vt.....	250	(21)
Fine-grained calcite, Laas, Tyrol.....	190	(15)
Pink fossiliferous, Knoxville, Tenn.....	180	(21)
Graphitic, Albertson, Vt.....	170	(21)
Saccharoidal calcite, Carrara, Italy.....	170	(15)
Karstmarmor, Nabresina, Istria.....	170	(15)
Fossiliferous, Plattsburg, N. Y.....	150	(21)
Dolomitic, Beaverdam, Md.....	150	(21)
Dolomitic, Lee, Mass.....	130	(21)
Coarse calcite, Ball Ground, Ga.....	110	(21)
Saccharoidal calcite, West Rutland, Vt.....	80	(21)

## Granite, Av. Range—100 to 200

Fine-grained biotite, Mauthausen, Austria....	230	(4)
Fine-grained biotite, Schwarzwasser, Poland..	180	(15)
Hornblende, Cape Ann, Mass.....	170	(22)
Biotite, Millbridge, Maine.....	140	(18)
Biotite, Baveno, Italy.....	110	(15)
Biotite, Gefrees, Franconia.....	80	(4)

## Sandstone, Av. Range—25 to 125

Flagstone, Lacyville, Pa.....	160	(21)
Quartzitic, Potsdam, N. Y.....	130	(21)
Triassic, Hummelstown, Pa.....	80	(21)
Feldspathic, McDermott, Ohio.....	80	(21)
Berea grit, Amherst, Ohio.....	50	(21)

## Limestone, Av. Range—75 to 125

Arenaceous dolomite, Kasota, Minn.....	150	(21)
Compact earthy, Cassville, Mo.....	140	(21)
Flinty, Buffalo, N. Y.....	100	(41)
Pure white oolitic, Kehlheim, Bavaria.....	90	(4)
Oolitic, Bedford, Ind.....	80	(21)
Muschelkalk, Randersacker, Bavaria.....	70	(4)

## TENSILE STRENGTH

kg cm<sup>-2</sup>

## Slate

Pen Argyl, Pa.....	250	(11)
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## Marble, Av. Range—30 to 90

Hematitic dolomite, Swanton, Vt.....	160	(21)
Carbonaceous, Isle LaMotte, Vt.....	90	(21)
Graphitic calcite, Albertson, Vt.....	90	(21)
Pink fossiliferous, Plattsburg, N. Y.....	90	(21)
Karstmarmor, Nabresina, Istria.....	90	(15)
Fine-grained, Laas, Tyrol.....	60	(15)
Coarse gr. calcite, Ball Ground, Ga.....	50	(21)
Dolomite, Parsberg, Bavaria.....	50	(4)
Saccharoidal calcite, Carrara, Italy.....	40	(15)
Dolomite, S. Dover, N. Y.....	30	(21)
Saccharoidal calcite, W. Rutland, Vt.....	30	(21)
Dolomite, Rehburg, Franconia.....	20	(4)

## Serpentine

Roxbury, Vt.....	110	(21)
Einsiedel, Bohemia.....	100	(15)
Hollysprings, Ga.....	100	(21)
Weisen, Tyrol.....	60	(15)

## Limestone, Av. Range—30 to 60

Compact earthy, Cassville, Mo.....	90	(21)
Compact earthy, Phenix, Mo.....	80	(21)
Arenaceous dolomite, Kasota, Minn.....	50	(21)
Buff oolitic, Bedford, Ind.....	30	(10)
Oolitic, Rockwood, Ala.....	30	(21)
Aluminous dolomite, Mantorville, Minn.....	20	(21)

## Granite, Av. Range—30 to 50

Gneissoid, St. Gothard Tunnel.....	40	(4)
Biotite, Hausenberg, Bavaria.....	40	(4)
Fine-grained, Schwarzwasser, Poland.....	40	(15)
Biotite, Baveno, Italy.....	40	(15)

## Sandstone, Av. Range—10 to 30

Feldspathic, McDermott, Ohio.....	40	(21)
Asphaltic, Liberal, Mo.....	20	(8)
Fine-grained variegated, Murgtal, Baden.....	20	(4)
Triassic, E. Longmeadow, Mass.....	20	(21)
Variegated, Kronach, Bavaria.....	10	(4)
Argillaceous, Hochberg, Bavaria.....	10	(4)
Glauconitic, Ihrlerstein Bavaria.....	10	(4)

## Trachyte

Spitzberg, Bohemia.....	40	(15)
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## RESISTANCE TO ABRASION ("HARDNESS") (19)

The hardness values were determined by subjecting cylindrical specimens 2.5 cm in diameter to the abrasive action of crushed and graded quartz which is fed upon a revolving steel disc. The coefficient of hardness equals  $20 - \frac{1}{2} \frac{w}{v}$  where  $w$  is the weight of specimen worn away by 1000 revolutions of the disc.

**Rhyolite, Av. Range—18 to 20**

Adams Co., Pa.....	≤ 20
Milton, Calif.....	≤ 20
Boise, Idaho.....	15

**Basalt, Av. Range—17 to 19**

Nephelite, Austin, Texas.....	19
Olivine, Cliffs, Wash.....	18

**Diabase, Av. Range—17 to 19**

Upper Nyack, N. Y.....	19
Ansonia, Conn.....	18

**Quartzite, Av. Range—16 to 19**

Roanoke, Va.....	19
Greenbank, Del.....	18

**Gabbro, Av. Range—16 to 18**

St. Peters, Pa.....	19
York Haven, Pa.....	18

**Trachyte**

Colorado Springs, Colo.....	19
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**Chert**

Chockie, Okla.....	19
Provo, Utah.....	17

**Amphibolite**

Wilmington, Del.....	19
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**Granite, Av. Range—17 to 19**

Biotite, Vinal Haven, Maine.....	19
Biotite, Barre, Vt.....	19
Hornblende, Beverly, Mass.....	19
Aplitic, Richmond, Va.....	18
Biotite, Mt. Airy, N. C.....	18
Quartz monzonite, Milford, N. H.....	18

**Slate, Av. Range—12 to 18**

Clay, Berks Co., Pa.....	19
Siliceous, Montgomery Co., Pa.....	18
Calcareous, Waynesboro, Va.....	12
Heber Springs, Ark.....	9

**Diorite, Av. Range—16 to 19**

Bakersfield, Calif.....	19
Granite Falls, Wash.....	18
Glen Mills, Pa.....	17

**Gneiss, Av. Range—16 to 19**

Hornblende, Middle Valley, N. J.....	19
Sericite, Atlanta, Ga.....	18
Biotite, Hanover, N. H.....	18
Diorite, Derwood, Md.....	18
Pyroxene, Little Falls, N. Y.....	17

**Schist, Av. Range—15 to 18**

Quartz hornblende, Havre de Grace, Md.....	19
Sericite, Atlanta, Ga.....	18
Quartzite, Haverhill, N. H.....	18
Muscovite, Charlottesville, Va.....	17

**Andesite**

Elbe, Wash.....	18
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**Syenite**

Vera Cruz, Pa.....	18
Charlottesville, Va.....	17

**Sandstone, Av. Range—12 to 18**

Argillaceous, Culpeper, Va.....	18
Ferruginous, Manassas, Va.....	18
Calcareous, Huntington, W. Va.....	16
Argillaceous, Salford, Pa.....	16
Chloritic, Warren, R. I.....	15
Ferruginous, Shreveport, La.....	14
Feldspathic, Parkersburg, W. Va.....	12
Bituminous, Provo, Utah.....	6
Ferruginous, Marshall, Texas.....	3

**Serpentine, Av. Range—12 to 16**

Rockville, Md.....	18
Blue Mountain, Pa.....	15
Newark, Calif.....	12

**Limestone, Av. Range—12 to 17**

Siliceous, Coyote, Calif.....	17
Carbonaceous, Petersburg, Ind.....	17
Fossiliferous, East Smithfield, Pa.....	16
Dolomitic, Huntington, W. Va.....	15
Crystalline, New Decatur, Ala.....	15
Dolomite, Joliet, Ill.....	14
Travertine, Damascus, Va.....	12
Argillaceous, Pontoosue, Ill.....	9
Bituminous, Ravia, Okla.....	3

**Marble, Av. Range—10 to 16**

Hematitic dolomite, Burlington, Vt.....	17
Dolomitic, Port Kennedy, Pa.....	15
Graphitic calcite, Regal, N. C.....	14
Calcite, Ball Ground, Ga.....	11
Siliceous, Texas, Md.....	8

**Tuff**

Andesite, Petaluma, Calif.....	5
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**Steatite**

New London, N. C.....	4
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**IMPACT HARDNESS ("TOUGHNESS") (19)**

The toughness values were determined by subjecting cylindrical specimens 2.5 cm high by 2.5 cm diameter to the impact produced by the fall of a 2 kg hammer upon a steel plunger, the lower end of which is spherical and rests on the test piece. The weight is first dropped from a height of 1 cm which is increased 1 cm for each blow until the specimen breaks. The toughness is recorded as the height of the last hammer fall.

**Slate, Av. Range—10 to 25**

Clay, Berks Co., Pa.....	56
Indurated, Green Lane, Pa.....	40
Micaceous, Green Lane, Pa.....	17
Heber Springs, Ark.....	16
Siliceous, Montgomery Co., Pa.....	11
Calcareous, Waynesboro, Va.....	10

**Sandstone, Av. Range—5 to 20**

Ferruginous, Manassas, Va.....	47
Feldspathic, Little Rock, Ark.....	37
Ferruginous, Berks Co., Pa.....	35
Argillaceous, Culpeper, Va.....	24
Chloritic, Warren, R. I.....	24
Calcareous, Monroe, N. Y.....	19
Argillaceous, Hughesville, Pa.....	13



**Sandstone.—(Continued)**

Calcareous, Harrisburg, Pa. ....	13
Ferruginous, Shreveport, La. ....	8
Conglomerate, Sullivan Co., Pa. ....	8
Calcareous, Huntington, W. Va. ....	7
Feldspathic, Parkersburg, W. Va. ....	6
Argillaceous, Salford, Pa. ....	6
Bituminous, Provo, Utah. ....	6
Ferruginous, Marshall, Texas. ....	3

**Rhyolite, Av. Range—5 to 25**

Adams Co., Pa. ....	42
Milton, Calif. ....	20
Boise, Idaho. ....	6

**Diorite, Av. Range—8 to 25**

Bakersfield, Calif. ....	36
Granite Falls, Wash. ....	17
Glen Mills, Pa. ....	12

**Schist, Av. Range—8 to 25**

Chlorite epidote, Haw River, N. C. ....	34
Quartz hornblende, Havre de Grace, Md. ....	19
Sericite, Atlanta, Ga. ....	10
Quartzite, Haverhill, N. H. ....	10
Muscovite, Charlottesville, Va. ....	7
Biotite, Leominster, Mass. ....	6

**Diabase, Av. Range—5 to 30**

Ansonia, Conn. ....	32
Upper Nyack, N. Y. ....	23

**Granite, Av. Range—5 to 18**

Hornblende, Beverly, Mass. ....	31
Coarse biotite, Vinal Haven, Maine. ....	12
Biotite, Barre, Vt. ....	9
Quartz monzonite, Milford, N. H. ....	8
Aplitic, Richmond, Va. ....	8
Biotite, Mt. Airy, N. C. ....	7
Muscovite, Stone Mountain, Ga. ....	7

**Quartzite, Av. Range—5 to 25**

Greenbank, Del. ....	30
Courtland, Minn. ....	22
Rockville, Pa. ....	20
Roanoke, Va. ....	14

**Basalt, Av. Range—5 to 30**

Hoquiam, Wash. ....	27
Nephelite, Austin, Texas. ....	24
Olivine, Cliffs, Wash. ....	18
Lind, Wash. ....	14

**Gneiss, Av. Range—5 to 15**

Hornblende, Middle Valley, N. J. ....	26
Pyroxene, Little Falls, N. Y. ....	18
Plagioclase, Clinton Co., N. Y. ....	10
Sericite, Atlanta, Ga. ....	8
Chlorite, East Providence, R. I. ....	8
Diorite, Derwood, Md. ....	7
Biotite, Hanover, N. H. ....	6

**Chert**

Chockie, Okla. ....	25
Provo, Utah. ....	6

**Limestone, Av. Range—5 to 15**

Dolomite, Springfield, Mo. ....	21
Carbonaceous, Petersburg, Ind. ....	20
Dolomitic, Washington, Pa. ....	14
Fossiliferous, East Smithfield, Pa. ....	10
Siliceous, Coyote, Calif. ....	8
Dolomitic, Huntington, W. Va. ....	8
Dolomite, Joliet, Ill. ....	8
Crystalline, New Decatur, Ala. ....	7
Cherty, Akron, N. Y. ....	7
Bituminous, Ravia, Okla. ....	6
Shell, Fort Myers, Fla. ....	6
Argillaceous, Pontoosuc, Ill. ....	4
Travertine, Damascus, Va. ....	4

**Trachyte**

Colorado Springs, Colo. ....	21
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**Tuff**

Basalt, Rio Piedras, Porto Rico. ....	20
Andesite, Petaluma, Calif. ....	5

**Amphibolite**

Wilmington, Del. ....	18
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**Marble, Av. Range—2 to 10**

Hematitic dolomite, Burlington, Vt. ....	18
Dolomitic, Port Kennedy, Pa. ....	5
Graphitic calcite, Regal, N. C. ....	4
Siliceous, Texas, Md. ....	3
Calcite, Ball Ground, Ga. ....	2

**Serpentine, Av. Range—8 to 15**

Rockville, Md. ....	17
Blue Mountain, Pa. ....	11
Newark, Calif. ....	6

**Gabbro, Av. Range—8 to 22**

St. Peters, Pa. ....	17
York Haven, Pa. ....	15

**Syenite, Av. Range—10 to 15**

Vera Cruz, Pa. ....	16
Spartanburg, S. C. ....	10
Charlottesville, Va. ....	10

**Andesite**

Augite, Elbe, Wash. ....	9
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**Steatite**

New London, N. C. ....	6
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**ELASTICITY**

Young's Modulus  
(Dynes cm<sup>-2</sup>) × 10<sup>-11</sup>

Example: For oolitic Bedford limestone, 180,000,000,000 dyne per sq. cm (10).

**Schist**

Chlorite, Chichibu, Japan. ....	12	(24)
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**Limestone, Av. Range—3 to 6**

Schalstein, Rickuchyu, Japan. ....	11	(24)
Fossiliferous, Montreal, Canada. ....	6.4	(1)
Impure calcite, Carthage, Mo. ....	5.4	(21)
Arenaceous dolomite, Kasota, Minn. ....	4.0	(21)
Oolitic, Rockwood, Ala. ....	3.8	(21)
Aluminous, Mantorville, Minn. ....	3.0	(21)

**Limestone.—(Continued)**

Oolitic, Russellville, Ala.....	2.9	(21)
Oolitic, Bedford, Ind.....	1.8	(10)

**Gabbro**

New Glasgow, Quebec.....	11	(1)
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**Marble, Av. Range—5 to 7**

Carbonaceous, Isle LaMotte, Vt.....	10	(21)
Belgian black, Dinant, Belgium.....	7.2	(1)
Hematitic dolomite, Swanton, Vt.....	7.0	(21)
Graphitic calcite, Albertson, Vt.....	6.3	(21)
Fossiliferous, Knoxville, Tenn.....	6.2	(1)
Saccharoidal calcite, Carrara, Italy.....	5.5	(1)
Saccharoidal calcite, Rutland, Vt.....	5.2	(1)
Pink fossiliferous, Plattsburg, N. Y.....	5.0	(21)

**Diabase**

Sudbury, Ontario.....	9.5	(1)
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**Slate, Av. Range—6 to 9**

Siliceous, Granville, N. Y.....	9.0	(21)
Sandy, Rickuchyu, Japan.....	8.2	(24)
Calcareous, Pen Argyl, Pa.....	6.2	(11)
Clay, Tanba, Japan.....	3.2	(24)

**Anorthosite**

New Glasgow, Quebec.....	8.2	(1)
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**Essexite**

Mt. Johnson, Quebec.....	6.7	(1)
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**Serpentine (Peridotite)**

Kuzi, Japan.....	6.6	(24)
Roxbury, Vt.....	5.8	(21)
Hollysprings, Ga.....	3.3	(21)

**Syenite (Nephelite)**

Montreal, Canada.....	6.3	(1)
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**Granite, Av. Range—4 to 6**

Biotite, Peterhead, Scotland.....	5.7	(1)
Biotite, Lake Lilly, N. B.....	5.6	(1)
Light gray hornblende, Rockport, Mass.....	5.5	(41)
Quartz monzonite, Westerly, R. I.....	5.1	(1)
Riebeckite aegirite, Quincy, Mass.....	5.0	(1)
Biotite, Aberdeen, Scotland.....	5.0	(5)
Biotite, Baveno, Italy.....	4.7	(1)
Biotite muscovite, Sanstead, Canada.....	3.9	(1)

**Steatite**

Arrington, Va.....	3.9	(21)
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**Dolomite**

Yellow, Anston, Yorkshire.....	3.4	(5)
Siliceous, Mansfield, Nottingham.....	2.3	(5)

**Rhyolite**

Izu, Japan.....	2.5	(24)
Kozuke, Japan.....	1.9	(24)

**Tuff**

Rhyolite, Iyo, Japan.....	2.1	(24)
Rhyolite, Mikawa, Japan.....	1.8	(24)
Andesite, Echizen, Japan.....	1.3	(24)
Rhyolite, Iwashiro, Japan.....	1.1	(24)
Izu, Japan.....	0.67	(24)
Rhyolite, Tochigi, Japan.....	0.20	(24)

**Sandstone**

Feldspathic, Cleveland, Ohio.....	1.6	(1)
Triassic, East Longmeadow, Mass.....	1.6	(21)
Bluestone, McDermott, Ohio.....	1.3	(21)

**BULK DENSITY**g cm<sup>-3</sup>**Basalt, Nephelite**

Austin, Texas.....	3.19	(19)
Debus, Bohemia.....	3.06	(12)
Lind, Wash.....	2.94	(19)

**Gabbro**

York Haven, Pa.....	3.04	(19)
Rice Pt., Duluth, Minn.....	2.79	(9)

**Gneiss, Av. Range—2.7 to 2.95**

Hornblende, Port Deposit, Md.....	3.04	(19)
Diorite, Amherst Co., Va.....	2.94	(19)
Pyroxene, Little Falls, N. Y.....	2.90	(19)
Chlorite, E. Providence, R. I.....	2.80	(19)
Sericite, Havre de Grace, Md.....	2.69	(19)
Biotite, Ansonia, Conn.....	2.69	(19)
Chloritic sericite, Potomac, Md.....	2.69	(19)

**Breccia**

Basalt, Culpeper, Va.....	3.00	(19)
Volcanic, Boulder Canyon, Ariz.....	2.46	(21)
Rhyolite, Silver Cliff, Calif.....	2.14	(19)

**Diabase**

Taylor's Falls, Minn.....	3.00	(13)
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**Schist, Av. Range—2.7 to 2.95**

Chlorite, Chichibo, Japan.....	2.97	(24)
Talc, Prov. Awa, Japan.....	2.94	(40)
Chlorite epidote, Haw River, N. C.....	2.80	(19)
Hornblende, Port Deposit, Md.....	2.73	(19)
Biotite, Atlanta, Ga.....	2.72	(19)
Sericite, Leominster, Mass.....	2.69	(19)
Quartzite, San Pedro, Calif.....	2.64	(19)

**Steatite**

Arrington, Va.....	2.97	(21)
New London, N. C.....	2.85	(19)

**Marble, Av. Range—2.7 to 2.85**

Coarse-grained dolomite, Texas, Md.....	2.86	(28)
Dolomitic, Lee, Mass.....	2.86	(21)
Small crystal dolomite, South Dover, N. Y.....	2.86	(21)
Hematitic dolomite, Swanton, Vt.....	2.83	(21)
Carbonaceous, Isle LaMotte, Vt.....	2.76	(21)
Magnesian, Gouverneur, N. Y.....	2.74	(21)
Coarse-grained calcite, Marblehill, Ga.....	2.72	(21)
Saccharoidal calcite, Rutland, Vt.....	2.71	(21)
Graphitic calcite, Albertson, Vt.....	2.71	(21)
Carbonaceous, Glens Falls, N. Y.....	2.70	(13)
Red and white, Cerfontaine, Belgium.....	2.21	(2)

**Serpentine—Av. Range—2.7 to 2.8**

Hollysprings, Ga.....	2.84	(21)
Peridotite, Kuzi, Japan.....	2.82	(24)
Roxbury, Vt.....	2.80	(21)
Rockville, Md.....	2.69	(19)
Auburn, Calif.....	2.54	(38)



**Limestone, Av. Range—2.3 to 2.7**

Dolomite, Springfield, Mass.....	2.80	(19)
Compact dolomite, Red Wing, Minn.....	2.75	(9)
Argillaceous, Clarksburg, W. Va.....	2.75	(19)
Argillaceous, St. Paul, Minn.....	2.71	(9)
Aluminous, Minneapolis, Minn.....	2.71	(9)
Travertine, Damascus, Va.....	2.69	(19)
Compact earthy, Cassville, Mo.....	2.66	(21)
Vesicular, Mantorville, Minn.....	2.65	(21)
Siliceous, Petersburg, Ind.....	2.64	(19)
Lithographic, Solenhofen, Bavaria.....	2.60	(7)
Arenaceous dolomite, Kasota, Minn.....	2.57	(21)
Pitted dolomite, Jefferson City, Mo.....	2.55	(8)
Compact, hard, Lias, France.....	2.40	(36)
Bituminous, Marblehead, Ohio.....	2.40	(13)
Magnesian, impure, Andalusia, Ill.....	2.34	(35)
Gray oolitic, Bedford, Ind.....	2.32	(21)
Buff oolitic, Bedford, Ind.....	2.28	(21)
Oolitic, Caen, Normandy.....	1.90	(13)

**Slate, Av. Range—2.7 to 2.8**

Calcareous, Pen Argyl, Pa.....	2.80	(11)
Siliceous, Granville, N. Y.....	2.76	(11)
Sandy, Rikuchyu, Japan.....	2.64	(24)
Clay, Mikawa, Japan.....	2.44	(24)

**Diorite**

Boulder Canyon, Ariz.....	2.77	(21)
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**Anorthosite**

Au Sable Forks, N. Y.....	2.75	(26)
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**Quartzite**

Pipestone, Minn.....	2.73	(45)
White Haven, Pa.....	2.67	(21)
E. Sioux Falls, S. D.....	2.64	(21)

**Syenite, Av. Range—2.6 to 2.7**

Coarse light-colored, Watab, Minn.....	2.73	(9)
Fine-grained gray, Sauk Rapids, Minn.....	2.71	(9)
Fine-grained gray, East St. Cloud, Minn.....	2.70	(9)
Porphyry, Pulaski Co., Ark.....	2.69	(34)
Fine-grained red, Beaver Bay, Minn.....	2.65	(9)
Red, East St. Cloud, Minn.....	2.63	(9)
Gray quartzose, East St. Cloud, Minn.....	2.63	(9)

**Granite, Av. Range—2.65 to 2.7**

Coarse biotite, Vinal Haven, Maine.....	2.72	(13)
Riebeckite-aegirite, Quincy, Mass.....	2.70	(13)
Biotite gneiss, Port Deposit, Md.....	2.68	(21)
Anorthosite, Au Sable Forks, N. Y.....	2.65	(13)
Coarse biotite, Vinal Haven, Maine.....	2.65	(21)
Coarse biotite, Stony Creek, Conn.....	2.65	(13)
Muscovite, Stone Mountain, Ga.....	2.63	(21)
Hornblende, Bay of Fundy, N. B.....	2.60	(13)

**Chert**

Provo, Utah.....	2.69	(19)
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**Felsite**

Beaver Bay, Minn.....	2.69	(9)
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**Sandstone, Av. Range—2.2 to 2.6**

Chloritic, Warren, R. I.....	2.69	(19)
Feldspathic, Portsmouth, R. I.....	2.68	(19)
Brown Potsdam, Fond du Lac, Wis.....	2.52	(9)
Ferruginous, Manassas, Va.....	2.52	(19)

**Sandstone.—(Continued)**

Argillaceous, Logan, Ohio.....	2.50	(19)
Triassic, Belleville, N. J.....	2.26	(13)
Brownstone, Edinburgh, Scotland.....	2.26	(13)
Calcareous, Warrensburg, Mo.....	2.21	(8)
Triassic, East Longmeadow, Mass.....	2.17	(21)

**Rhyolite**

Dunbarton, Calif.....	2.69	(19)
Kozuke, Japan.....	2.46	(24)
Izu, Japan.....	2.10	(24)

**Tuff**

Rhyolite, Lake Shore, Calif.....	2.63	(19)
Rhyolite, Iyo, Japan.....	2.33	(24)
Basalt, Holcomb, Wash.....	2.29	(19)
Rhyolite, Douglas Co., Colo.....	2.19	(25)
Andesite, Petaluma, Calif.....	1.84	(19)
Rhyolite, Tochigi, Japan.....	1.37	(24)

**Andesite**

Echizen, Japan.....	2.42	(24)
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**POROSITY**

Per cent of pore space

**Diabase**

Hohenberg, Bavaria.....	0.2	(2)
Hohenberg, Bavaria, green.....	0.5	(12)
Wiesbaden, Germany.....	1.2	(12)

**Granite, Av. Range—0.5 to 1.5 %**

Biotite, Peterhead, Scotland.....	0.3	(2)
Biotite, Lysekil, Sweden.....	0.8	(12)
Biotite, Karlskrona, Sweden.....	1.0	(12)
Biotite, Malmö, Sweden.....	1.3	(12)
Hornblende, Pontresina, Switzerland.....	2.6	(39)

**Basalt**

Lichtenau, Westphalia, blue.....	0.4	(12)
Debus, Bohemia.....	0.5	(12)

**Marble, Av. Range—0.5 to 1.0 %**

Graphitic calcite, Albertson, Vt.....	0.4	(21)
Saccharoidal calcite, Rutland, Vt.....	0.4	(21)
Carbonaceous, Isle La Motte, Vt.....	0.5	(21)
Hematitic dolomite, Swanton, Vt.....	0.5	(21)
Dolomitic, Beaverdam, Md.....	0.6	(21)
Dolomitic, Lee, Mass.....	0.7	(21)
Black, Dinant, Belgium.....	0.7	(2)
Fossiliferous, Meadow, Tenn.....	0.8	(21)
Saccharoidal calcite, Carrara, Italy.....	0.8	(2)
Red and white, Cerfontaine, Belgium.....	0.9	(2)
Breccia, Besazio, Switzerland.....	1.5	(39)
Magnesian, Ollon, Switzerland.....	1.8	(39)

**Limestone, Av. Range—3.0 to 15 %**

Glaucinitic, Sachseln, Switzerland.....	1.0	(39)
Compact, earthy, Cassville, Mo.....	2.0	(21)
Oolitic, St. Ursanne, Switzerland.....	4.8	(39)
Pitted dolomite, Jefferson City, Mo.....	8.3	(8)
Compact fossiliferous, Derbyshire.....	8.4	(2)
Oolitic, Bowling Green, Ky.....	16.0	(21)
Oolitic, Bedford, Ind.....	16.0	(21)
Schaumkalk, La Coudre, Switzerland.....	17.0	(39)
Bath oolite, Monks Park, Somerset.....	20.0	(2)

**Porphyry**

Quartz, Beutengrund, Silesia.....	1.4	(12)
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## Quartzite

White, E. Sioux Falls, S. Dak.....	1.5	(21)
Red, White Haven, Pa.....	1.6	(21)
Pink, Ashby-de-la-Zouch, England.....	2.9	(2)

## Sandstone, Av. Range—5 to 20%

Calcareous, Beckenried, Switzerland.....	1.9	(39)
Graywacke, Huttensteinach, S. Coburg-Gotha.....	3.7	(12)
Flagstone, Lacyville, Pa.....	5.6	(21)
Quartzitic, Potsdam, N. Y.....	6.7	(21)
Yellow grit, Leeds, England.....	12.0	(2)
Calcareous, Hummelstown, Pa.....	13.0	(21)
Brownstone, Portland, Conn.....	13.0	(21)
Calcareous, Mansfield, Nottingham.....	15.0	(2)
Calcareous, Warrensburg, Mo.....	17.0	(8)
Feldspathic, McDermott, Ohio.....	17.0	(21)
Triassic, East Longmeadow, Mass.....	19.0	(21)
Berea grit, Amherst, Ohio.....	20.0	(21)
Coarse grit, Glenmont, Ohio.....	22.0	(21)

## Gneiss

Two mica, Cresciano, Switzerland.....	2.5	(39)
Biotite, Castaneda, Switzerland.....	3.7	(39)
Muscovite, Osogna, Switzerland.....	4.4	(39)

## Gabbro

Randaual, Hanover.....	3.0	(12)
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## Breccia

Quartz, Mels, Switzerland.....	3.7	(39)
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## Diorite

Quartz, Pontresina, Switzerland.....	4.3	(39)
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## Serpentine

Peridotite, Hospenthal, Switzerland.....	6.0	(39)
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## Tuff

Calcareous, Oberdorf, Switzerland.....	17.0	(39)
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## COMPRESSIBILITY

$$\frac{1}{v} \frac{dv}{dP}, \text{ kg}^{-1} \times 10^{-6}$$

Example: For granite, the compressibility at a pressure of 2 000 kg cm<sup>-2</sup> is 0.000 0021 or 0.000 21% per kg.

Granite	at 2 000 kg per sq. cm.....	2.1	(44)
	at 10 000 kg per sq. cm.....	1.8	(44)
Basalt	at 2 000 kg per sq. cm.....	1.8	(44)
	at 10 000 kg per sq. cm.....	1.5	(44)
Marble	at 2 000 kg per sq. cm.....	1.4	(44)
	at 10 000 kg per sq. cm.....	1.4	(44)
Limestone 0 to 12 000 kg per sq. cm			
Lithographic	at 75°C.....	1.4	(7)
	at 30°C.....	1.3	(7)
Diabase	at 2 000 kg per sq. cm.....	1.2	(44)
	at 10 000 kg per sq. cm.....	1.2	(44)

## THERMAL EXPANSION

$$\frac{1}{l} \frac{\Delta l}{\Delta t}, \text{ deg}^{-1} \text{ C} \times 10^{-6}$$

Example: For Bedford limestone between 25 and 100°, 0.000 009 or 0.000 9% per °C.

## Limestone

Semi-crystalline, Somersetshire, England	20° to 100°	22	(2)
Semi-crystalline, Somersetshire, England	100 to 200	26	(2)
Semi-crystalline, Somersetshire, England	200 to 300	27	(2)
Oolitic, Bedford, Ind.....	25 to 100	9	(37)
Oolitic, Bedford, Ind.....	100 to 200	17	(37)

## Limestone.—(Continued)

Oolitic, Bedford, Ind.....	200 to 300	22	(37)
Dense fossiliferous, Derbyshire, England	20 to 100	9	(2)
Dense fossiliferous, Derbyshire, England	100 to 200	16	(2)
Derbyshire, England.....	200 to 300	21	(2)
Mt. Vernon, Ky.....	0 to 100	8.3	(41)
Dense fossiliferous, Mt. Vernon, Ky....	100 to 200	8.8	(41)
Oolitic, Bath, England.....	20 to 100	4.2	(2)
Oolitic, Bath, England.....	100 to 200	9.6	(2)
Oolitic, Bath, England.....	200 to 300	19	(2)

## Marble

Blue calcite, Rutland, Vt.....	25 to 100	16	(37)
Blue calcite, Rutland, Vt.....	100 to 200	25	(37)
Blue calcite, Rutland, Vt.....	200 to 300	29	(37)
White magnesian calcite, Pittsford, Vt...	25 to 100	14	(37)
White magnesian calcite, Pittsford, Vt...	100 to 200	23	(37)
White magnesian calcite, Pittsford, Vt...	200 to 300	25	(37)
Gray fossiliferous, Knoxville, Tenn....	25 to 100	10	(37)
Gray fossiliferous, Knoxville, Tenn....	100 to 200	22	(37)
Gray fossiliferous, Knoxville, Tenn....	200 to 300	27	(37)
Fine-grained, Couillet, Belgium.....	20 to 100	9.2	(2)
Fine-grained, Couillet, Belgium.....	100 to 200	19	(2)
Fine-grained, Couillet, Belgium.....	200 to 300	19	(2)
Saccharoidal calcite, Carrara, Italy....	20 to 100	8.8	(2)
Saccharoidal calcite, Carrara, Italy....	100 to 200	18	(2)
Saccharoidal calcite, Carrara, Italy....	200 to 300	24	(2)
Dolomitic, Lee, Mass.....	0 to 100	8.1	(41)
Dolomitic, Lee, Mass.....	100 to 200	13	(41)
Dense black, Dinant, Belgium.....	20 to 100	4.9	(2)
Dense black, Dinant, Belgium.....	100 to 200	10	(2)
Dense black, Dinant, Belgium.....	200 to 300	14	(2)
Coarse calcite, Marble Hill, Ga.....	0 to 100	3.6	(41)
Coarse calcite, Marble Hill, Ga.....	100 to 200	19	(41)

## Quartzite

Pink, Ashby-de-la-Zouch, England.....	20 to 100	16	(2)
Pink, Ashby-de-la-Zouch, England.....	100 to 200	20	(2)
Pink, Ashby-de-la-Zouch, England.....	200 to 300	20	(2)

## Sandstone

Yellow grit, Leeds, England.....	20 to 100	12	(2)
Yellow grit, Leeds, England.....	100 to 200	16	(2)
Yellow grit, Leeds, England.....	200 to 300	19	(2)
Calcareous, Nottingham, England.....	20 to 100	10	(2)
Calcareous, Nottingham, England.....	100 to 200	15	(2)
Calcareous, Nottingham, England.....	200 to 300	19	(2)
Triassic, Kibbe, Mass.....	0 to 100	10	(41)
Triassic, Kibbe, Mass.....	100 to 200	14	(41)
Triassic, Seneca Creek, Md.....	0 to 100	5	(41)

## Slate

Mica slate, Hydeville, Vt.....	0 to 100	12	(14)
Mica slate, Monson, Maine.....	0 to 100	9.4	(41)
Mica slate, Monson, Maine.....	100 to 200	9.7	(41)

## Granite

Quartz monzonite, Westerly, R. I.....	20 to 100	9	(42)
Quartz monzonite, Westerly, R. I.....	100 to 200	14	(42)
Quartz monzonite, Westerly, R. I.....	200 to 300	20	(42)
Biotite, Milford, Mass.....	0 to 100	7.6	(41)
Biotite, Milford, Mass.....	100 to 200	13	(41)
Gneissoid, Branford, Conn.....	0 to 100	7.2	(41)
Gneissoid, Branford, Conn.....	100 to 200	17	(41)
Muscovite-biotite, Troy, N. H.....	0 to 100	6.1	(41)
Muscovite-biotite, Troy, N. H.....	100 to 200	12	(41)



## Diabase

	20 to 100	6.3	(42)
	100 to 200	9	(42)
	200 to 300	12	(42)

## SPECIFIC HEAT

The heat capacity of building stones, irrespective of type, varies within the rather narrow limits of 0.7–0.95 joule per g or 0.18–0.23 cal, per g or BTU per lb. for the dry stone. An occasional higher value, such as 0.28 cal per g for a serpentine from Cornwall, Eng., has been reported (17, 40).

## THERMAL CONDUCTIVITY

Joules cm<sup>-2</sup> sec<sup>-1</sup> (°C, cm<sup>-1</sup>)

Room temperatures

## Quartzite

Variegated, Prov. Bungo, Japan.....	0.054	(40)
Prov. Hizen, Japan.....	.031	(40)

## Gneiss

Osogna, Turin.....	.034	(48)
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## Schist

Talc, Prov. Awa, Japan.....	.033	(40)
Granite, Simplon Tunnel.....	.027†§	(48)
Epidote, Prov. Awa, Japan.....	.018	(40)
Piedmontite, Prov. Awa, Japan.....	.009	(40)

Marble, Av. Range—0.02 to 0.03 (See also *infra*)

Black, Golzines, Belgium.....	.032	(30)
Dense fossiliferous, Knoxville, Tenn.....	.032	(30)
Saccharoidal, Japan.....	.030	(47)
Fine-grained yellow, Monte Arenti, Italy.....	.028	(30)
Breccia, Seravezza, Italy.....	.028	(30)
Carbonaceous, Isle LaMotte, Vt.....	.028	(30)
Yellow marble, Estremoz, Portugal.....	.028	(30)
Red marble, Devonshire, England.....	.023	(17)
Onyx, Mexico.....	.023	(30)
Green marble, Ireland.....	.023	(17)
Saccharoidal calcite, Carrara, Italy.....	.021	(30)
Vermont.....	.021	(30)

## Serpentine

Prov. Hitachi, Japan.....	.030	(40)
Red, Cornwall, England.....	.020	(17)

## Gabbro

Hornblende, Prov. Chikuzen, Japan.....	.030	(40)
Hornblende, Prov. Awadi, Japan.....	.018	(40)

## Sandstone, Av. Range—0.025 to 0.03 (See also p. 315)

Hard grit, Linton, England.....	.029*	(17)
Hard grit, Linton, England.....	.026†	(17)
Flagstone, Loch Rannoch.....	.027‡	(17)
Flagstone, Loch Rannoch.....	.021§	(17)
Feldspathic, Bristol, England.....	.027	(17)

\* Stone wet.

† Perpendicular to cleavage.

‡ Stone dry.

§ Parallel to cleavage.

## Limestone, Av. Range—0.02 to 0.025 (See also p. 315)

Dolomite, Mansfield, Nottingham.....	.029	(17)
Magnesian, South Shields, England.....	.024	(17)
Oolitic, Musashi, Japan.....	.022	(40)
Oolite, Caen, Normandy.....	.020	(17)
Dolomite, Prov. Buzen, Japan.....	.018	(40)
Gritty, Boniss Island.....	.015	(40)
Coral, Boniss Island.....	.009	(40)

## Conglomerate

Nagelfluë, St. Gallen.....	0.025	(48)
Calumet & Hecla Mine, Mich.....	.020	(48)

## Granite

Porphyry, Prov. Omi, Japan.....	.024	(40)
Biotite, Aberdeen, Scotland.....	.023	(17)
Biotite, Prov. Yamashiro, Japan.....	.022	(40)

## Diorite

Prov. Tanba, Japan.....	.023	(40)
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## Gneiss

Prov. Yamashiro, Japan.....	.021	(40)
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## Amphibolite

	.020	(40)
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## Porphyrite

Hornblende, Prov. Omi, Japan.....	.018	(40)
Augite, Prov. Kai, Japan.....	.016	(40)
Prov. Higo, Japan.....	.012	(40)

## Tuff

Liparite, Prov. Bitchu, Japan.....	.017	(40)
Liparite, Prov. Harima, Japan.....	.014	(40)
Prov. Yamato, Japan.....	.007	(40)
Breccia, Prov. Yamato, Japan.....	.007	(40)

## Rhyolite

Prov. Etchu, Japan.....	.015	(40)
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## Basalt (See also p. 315)

Prov. Tanba, Japan.....	.014	(40)
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## Andesite

Olivine pyroxene, Prov. Idzu, Japan.....	.013	(40)
Pyroxene, Prov. Satsuma, Japan.....	.006	(40)

## Travertine

Campagna Romana.....	.011	(48)
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## Lava

Mt. Vesuvius.....	.008	(48)
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## Shale

	.008	(40)
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## Marble

Alabama white marble of density 2.7 g cm<sup>-3</sup>, and sp. ht. 0.213 cal g<sup>-1</sup>/°C gave (49), 50–100°C, 0.0257; 100–200°C, 0.0206.

## THERMAL DIFFUSIVITY (40)

cm<sup>2</sup> sec<sup>-1</sup>

## Quartzite

Variegated, Prov. Bungo, Japan.....	0.031
Red, Prov. Bungo, Japan.....	.023

## Schist

Piedmontite, Prov. Awa, Japan.....	.027
Talc, Prov. Awa, Japan.....	.014
Epidote, Prov. Awa, Japan.....	.008

## Sandstone

Compact, Prov. Kawachi, Japan.....	.014
Feldspathic, Prov. Awa, Japan.....	.012

Granite	
Biotite, Prov. Yamashiro, Japan.....	0.013
Porphyritic, Prov. Omi, Japan.....	.012
Hornblende, Prov. Mikawa, Japan.....	.009
Two mica, Prov. Mikawa, Japan.....	.006
Gneiss	
Granite, Prov. Yamashiro, Japan.....	.013
Serpentine	
Peridotite, Prov. Hitachi, Japan.....	.013
Diorite	
Prov. Tanba, Japan.....	.012
Limestone	
Oolitic, Prov. Musashi, Japan.....	.011
Dolomite, Prov. Buzen, Japan.....	.008
Gritty, Boniss Island.....	.007
Coral, Boniss Island.....	.005
Marble ( <i>See also infra</i> )	
White calcite, Prov. Mino, Japan.....	.011
White, Alabama (49).....	.0106
Tuff	
Liparite, Prov. Harima, Japan.....	.009
Breccia, Prov. Yamato, Japan.....	.005
Pumiceous, Prov. Ugo, Japan.....	.004
Gabbro	
Hornblende, Prov. Awadi, Japan.....	.008
Rhyolite	
Prov. Etchu, Japan.....	.008

Basalt	
Prov. Tanba, Japan.....	0.007
Andesite	
Olivine, Prov. Idzu, Japan.....	.006
Pyroxene, Prov. Satsuma, Japan.....	.005
Shale	
	.004

## LITERATURE

(For a key to the periodicals see end of volume)

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## CLAYS

H. RIES

CONTENTS	MATIÈRES	INHALTSVERZEICHNIS	INDICE
Density.	Densité.	Dichte.	Densità.
Porosity.	Porosité.	Porosität.	Porosità.
Tensile strength.	Résistance à la traction.	Zugfestigkeit.	Resistenza alla trazione.
Transverse strength.	Résistance à la flexion.	Biegefestigkeit.	Resistenza alla flessione.
Modulus of rupture.	Module de rupture.	Bruchmodulus.	Modulo di rottura.
Drying shrinkage.	Retrait à la dessiccation.	Trockenschwindung.	Contrazione per essiccamento.
Firing shrinkage.	Retrait à la cuisson.	Brennschwindung.	Contrazione al fuoco.
Water of plasticity.	Eau de plasticité.	Anmachwasser.	Acqua di plasticità.
Fusion points.	Points de fusion.	Schmelzpunkte.	Punti di fusione.
Thermal reactions.	Réactions thermiques.	Thermische Reaktionen.	Reazioni termiche.
Specific heat.	Chaleur spécifique.	Spezifische Wärme.	Calore specifico.
Dehydration behavior.	Conduite à la déhydratation.	Verhalten bei der Entwässerung.	Comportamento alla disidratazione.
Refractive index.	Indice de réfraction.	Brechungsindex.	Indice di rifrazione.
Properties of Bentonite clays.	Propriétés des argiles de Bentonite.	Eigenschaften der Bentonite Tone.	Proprietà delle argille Bentonite.



LIST OF CLAYS AND THEIR INDEX NUMBERS  
For properties, *v.* Figs. 1, 2, 3

Index No.	Type of clay	Index No.	Type of clay
1	Allophane	40	Laclede Christy raw flint clay
2	Atlas	41	Maryland flint clay
3	American ball clay	42	Ohio flint clay
4	Dorset ball clay	43	Semi-flint clay
5	English blue ball clay	44	Gibbsite
6	English white ball clay	45	Glass pot clay
7	Tennessee ball clay	46	Glenboig fire clay
8	Ayrshire bauxitic clay	47	Halifax clay
9	Bentonite	48	Halloysite
10	Refractory bond clay	49	Helmstadt clay
11	Brazil, Ind., clay	50	Kaolinite
12	Brick clay	51	Kaolin
13	Common brick clay	52	Albsheim kaolin
14	Face brick clay	53	Amberg kaolin
15	Paving brick clay	54	Australian kaolin
16	Plastic clay for No. 1 fire brick, Md.	55	Crude kaolin
17	Plastic clay for No. 2 fire brick, Md.	56	Eger kaolin
18	Bunzlau clay	57	Geisenheim kaolin
19	Cornwall china clay	58	Georgia kaolin
20	English china clay	59	Halle kaolin
21	Crucible clay	60	North Carolina kaolin
22	Czechoslovakia clay	61	St. Yrieix kaolin
23	Diaspore clay	62	Texas kaolin
24	English fire clay	63	Washed kaolin
25	Farnley fire clay	64	White sedimentary kaolin
26	Grossalmerode fire clay	65	Zettlitz kaolin
27	Halle Saxony fire clay	66	Lower Kittanning clay
28	Kittanning No. 2 fire	67	Lower Mercer clay
29	Lischwitz fire	68	Sagger clay
30	Löthian fire	69	Sewer pipe clay
31	Maryland fire	70	Aluminous shale
32	Meissen fire	71	Galesburg, Ill. shale
33	Ohio fire	72	Illinois shale
34	Ohio plastic fire	73	Ohio shale
35	Vallendar fire	74	Stoneware clay
36	Flint clay for No. 1 fire brick, Ky.	75	Cleveland surface clay
37	Flint clay for No. 1 fire brick, Md.	76	Georgia surface clay
38	Flint clay for No. 2 fire brick, Md.	77	Ohio surface clay
39	Flint clay for No. 1 fire brick, Md. and Ky.	78	Tionesta clay
		79	Velten clay
		80	Plastic fire clay
		81	Flint clay

EFFECT OF FIRING ON TRANSVERSE STRENGTH OF CLAY (10)

Clay	*	Modulus of rupture			
		Dried at 110°C, lb. in. <sup>-2</sup>	Fired clay, hundred lb./in. <sup>2</sup>		
			Cone 6	Cone 8	Cone 10
Tionesta clay: Ellis, Muskingum County, Ohio.	{ R	390	46	67	38
	{ W	468	72	83	53
Tionesta clay: Crooksville, Perry County, Ohio.	{ R	179	20	30	20
	{ W	315	66	71	37
Lower Kittanning clay (unweathered): Roseville, Muskingum County, Ohio.	{ R	219	32	34	27
	{ W	320	86	87	75
Lower Kittanning clay: Toronto, Jefferson Co., Ohio.	{ R	384	28	23	23
	{ W	532	79	48	57

Clay	*	Modulus of rupture			
		Dried at 110°C, lb. in. <sup>-2</sup>	Fired clay, hundred lb./in. <sup>2</sup>		
			Cone 6	Cone 8	Cone 10
New Brighton, Beaver County, Pa.	{ R	194	29	31	19
	{ W	191	49	58	34
New Brighton, Beaver County, Pa.	{ R	195	26	33	15
	{ W	321	51	52	47
Fire brick, Lawrence County, Ohio.	{ R	325	41	51	30
	{ W	499	104	72	62
Nelsonville, Hocking County, Ohio.	{ R	247	16	35	20
	{ W	350	47	62	50
Lower Mercer clay: White Cottage, Muskingum County, Ohio.	{ R	132	30	32	17
	{ W	251	57	73	47
Mogadore, Summit County, Ohio.	{ R	143	20	23	22
	{ W	259	46	48	34
Semi-flint clay: Scioto Furnace, Scioto County, Ohio.	{ R	94	16	21	20
	{ W	270	37	74	27

\* R indicates run of mine, ground to pass a 20 mesh sieve. W indicates washed clay passing a 150 mesh sieve.

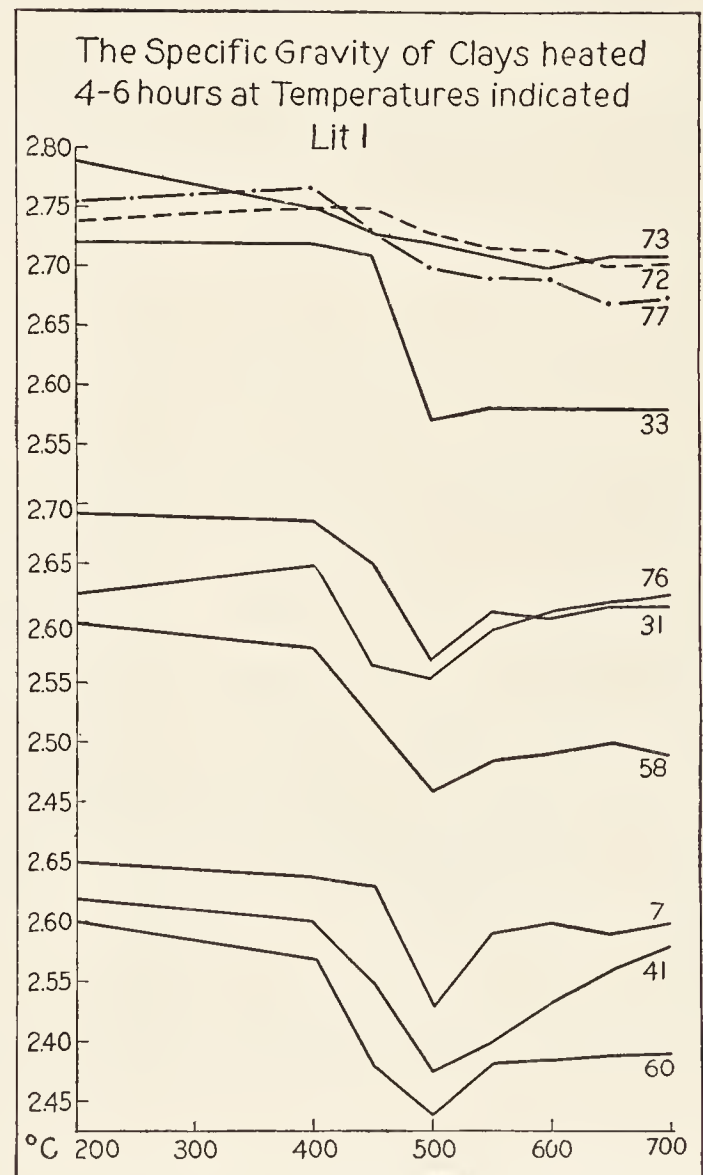
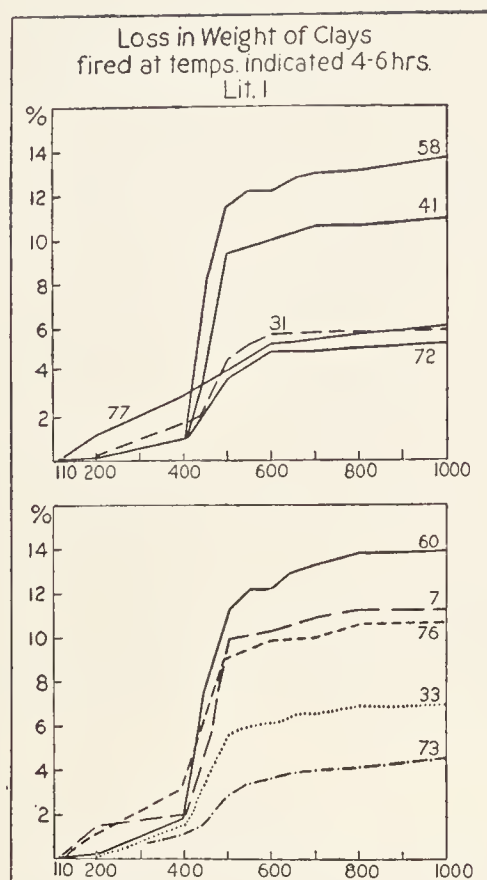


FIG. 4.



Fire Shrinkage (linear) of Diaspore and Gibbsite Clays (fired to temps. indicated)

%	1050	1100	1150	1200	1250	1300	1350	1400	1450	1500
50										
40										
30										
20										
10										
0										

Lit. 3

Porosities of Diaspore and Gibbsite Clays (fired to temps. indicated)

%	1050	1100	1150	1200	1250	1300	1350	1400	1450	1500
50										
40										
30										
20										
10										
0										

Bulk Specific Gravity of Clays (fired to temps. indicated)\*

	750	900	1000	1100	1150	1200	1250	1275	1300	1325	1350	1375	1400
2.5													
2.0													
1.5													
1.0													

\* Determined by formula  $\frac{D}{W-S}$  in which D=dry wt. W=saturated wt. S=saturated suspended wt.

True Specific Gravity of Clays (fired to temps. indicated) Determined with Pycnometer

	750	900	950	990	1000	1030	1050	1070	1090	1100	1110	1130	1150	1170	1190	1200	1210	1230	1250	1270	1290	1300	1370	1400
3.0																								
2.5																								
2.0																								
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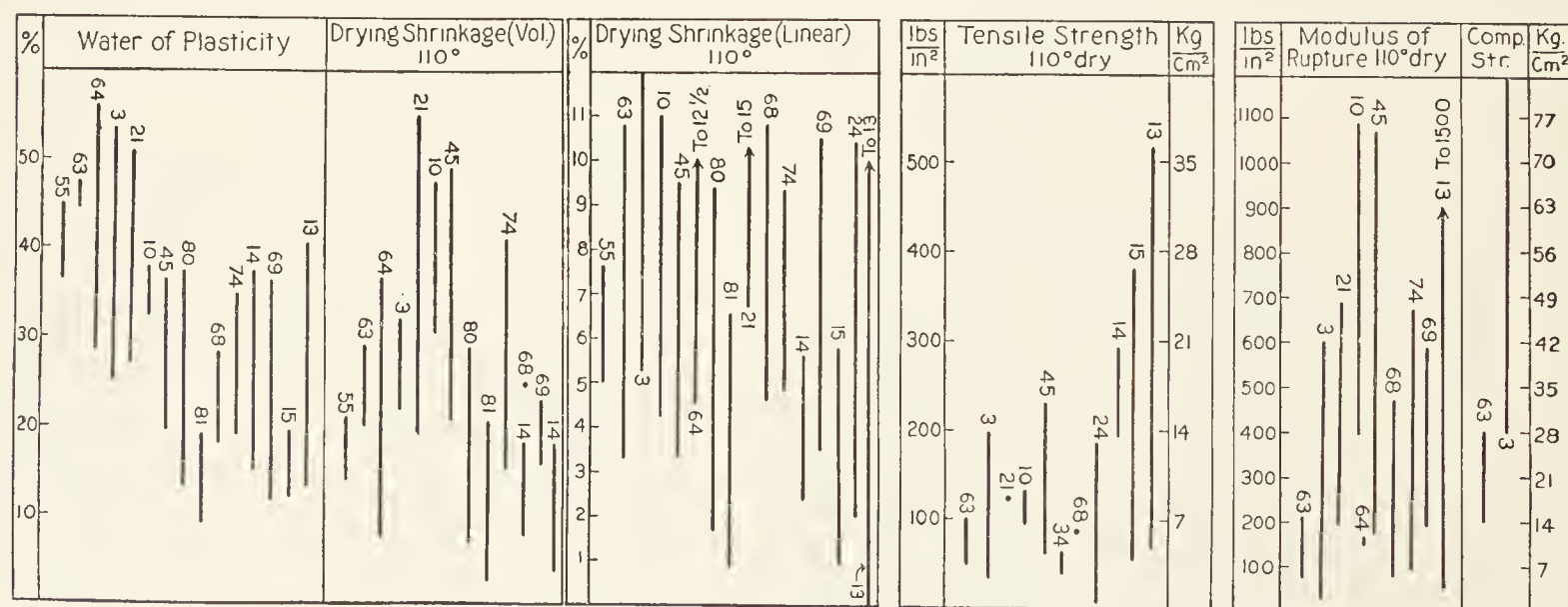


Fig. 1.



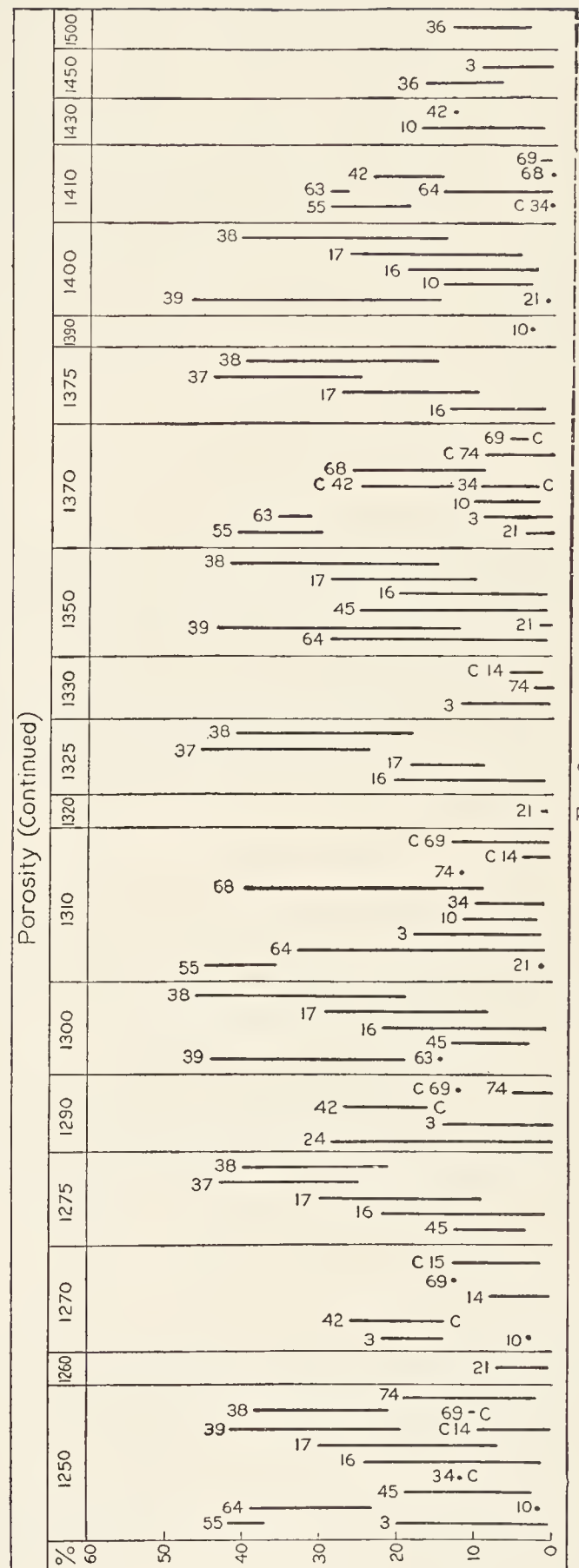
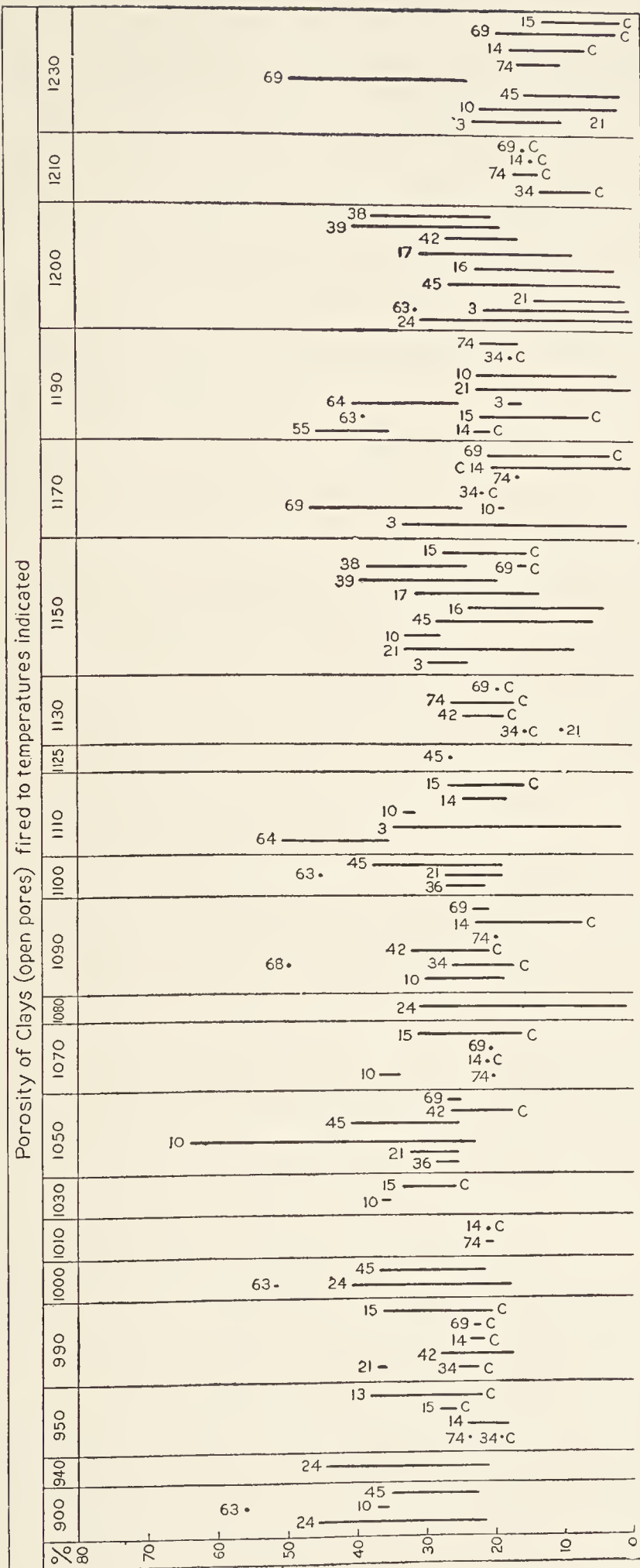


Fig. 2.

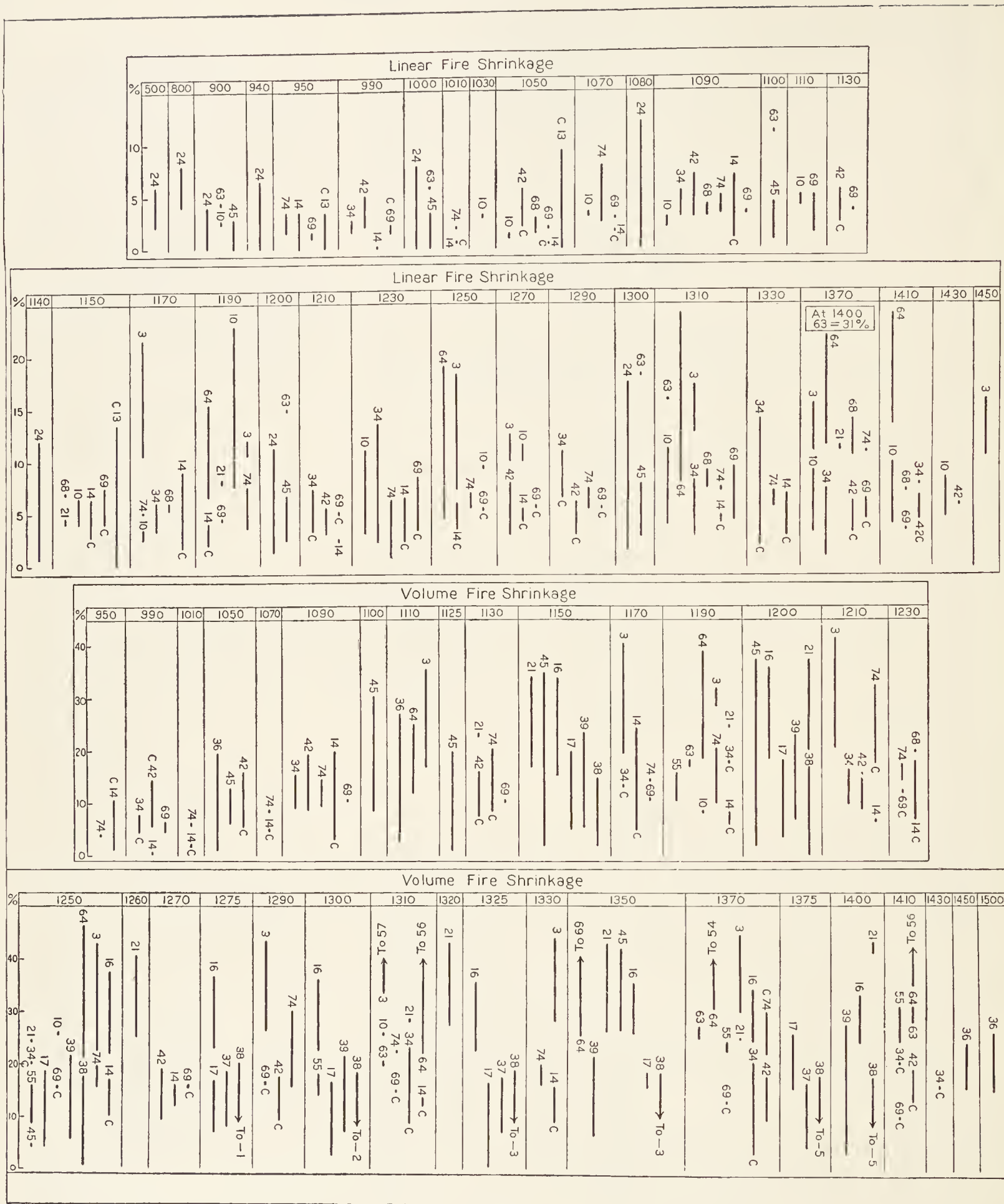


FIG. 3.



# LINEAR FIRE SHRINKAGE AND POROSITIES OF DIASPORE AND GIBBSITE CLAYS (3)

B. T. = burning temperature. S = shrinkage. Por. = Porosity

B. T., °C	% S	% Por.	B. T., °C	% S	% Por.
1050	0-13	39-54	1300	5-40	36-50
1100	1-13	40-53	1350	9-42	34-48
1150	2-18	40-60	1400	9-44	32-49
1200	2-27	37-55	1450	12-55	16-48
1250	4-38	38-51	1500	17-55	9-46

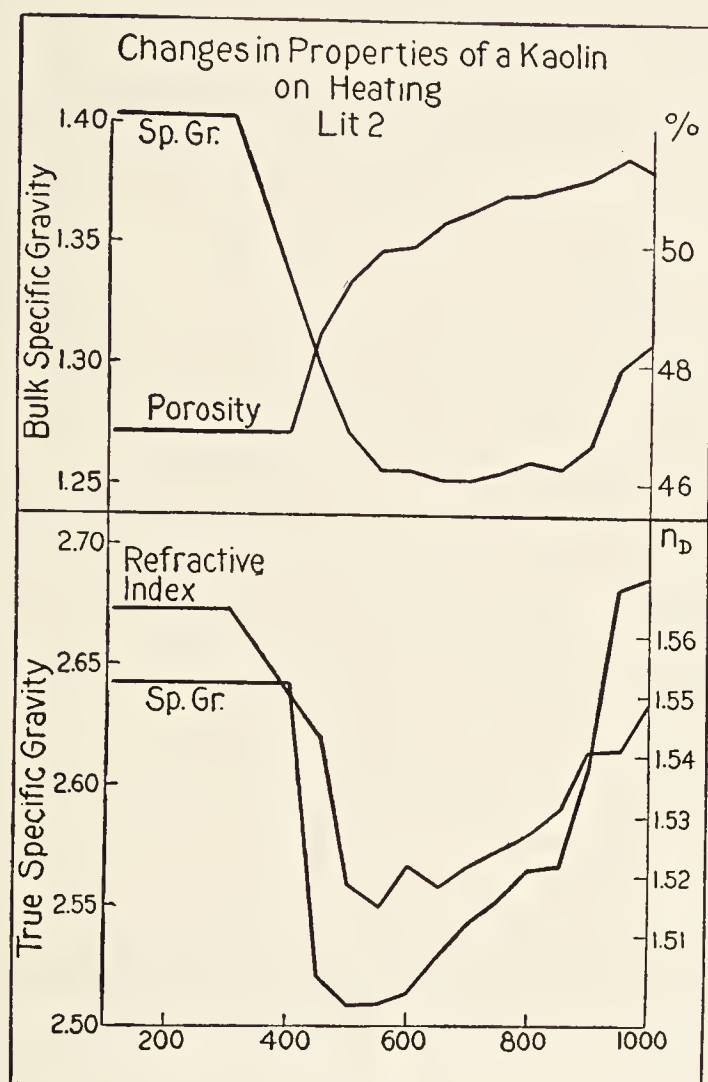


FIG. 5.

## FUSION POINT IN CONES

Clay	Seeger cone
Kaolin, washed.....	33 -35
White sedimentary, Ga. and S. C.....	34 -35
Ball clays.....	30 -35
Crucible clays.....	30 -
Refractory bond clays.....	28 -33
Glass pot clays.....	21½-32
Stoneware clays.....	18 -32
Plastic fire clays, various localities.....	27 -35
Md., bond in No. 2 fire brick.....	31 -32
Flint clays, Md.....	32 -35
Md., No. 2 fire brick.....	28 -31
Ohio.....	31 -32½
Sagger clays.....	27 -28
Face brick clays.....	17 -30½
Common brick clays.....	1 -10

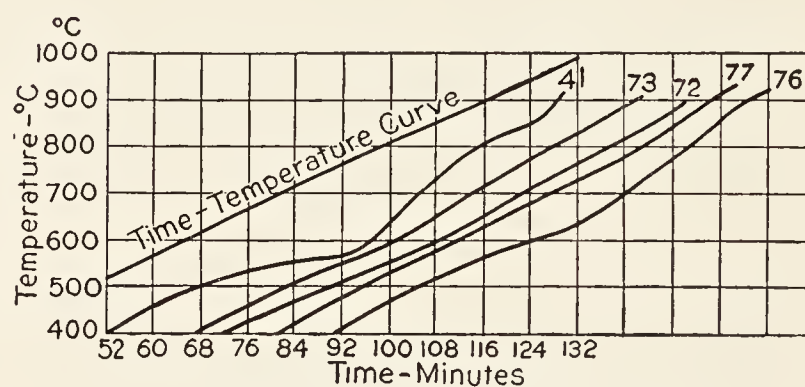
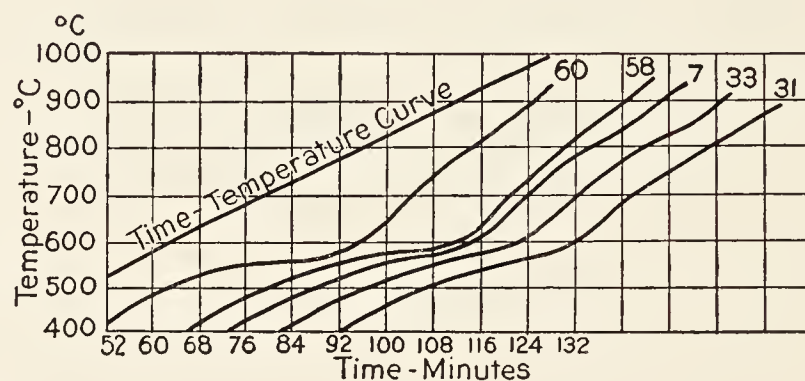


FIG. 6.—Heating curves of clays (1).

## WATER RATIOS TO CLAY VOLUME AND WEIGHT

Clay	Ratio of pore water to shrinkage water	% water in terms true clay volume	% shrinkage water in terms true clay volume	% pore water in terms true clay volume
Ball clays.....	0.64-1.10			
Crucible clays.....	0.56-1.36	69.5-132.5	37.2-84.8	40.5-55.1
Refractory bond clay			15.5	
Glass pot clays.....	0.65-1.54	53.4-132.5	26.8-77.4	26.6-59.4
Plastic fire clay, Md.				
No. 1 fire brick....	1.09-2.08			
No. 2 fire brick....	1.13-4.15			
Stoneware clay.....	0.61-1.16	75-90.6	37.1-55.6	34.0-45.0

## THERMAL REACTIONS IN CLAY WITH TEMPERATURES AT WHICH REACTIONS HAVE BEEN NOTED (2), cf. (7)

Clay	Endothermic, °C	Exothermic, °C
Kaolin.....	500	950
Ayrshire bauxitic clay.....	530	950
Dorset ball clay.....	110 500	920
Farnley fire clay.....	90 510	910
Atlas clay.....	80 490	930
Aluminous shale.....	90 510	920
Halifax clay after experimental electro-osmosis.....	90 520	915

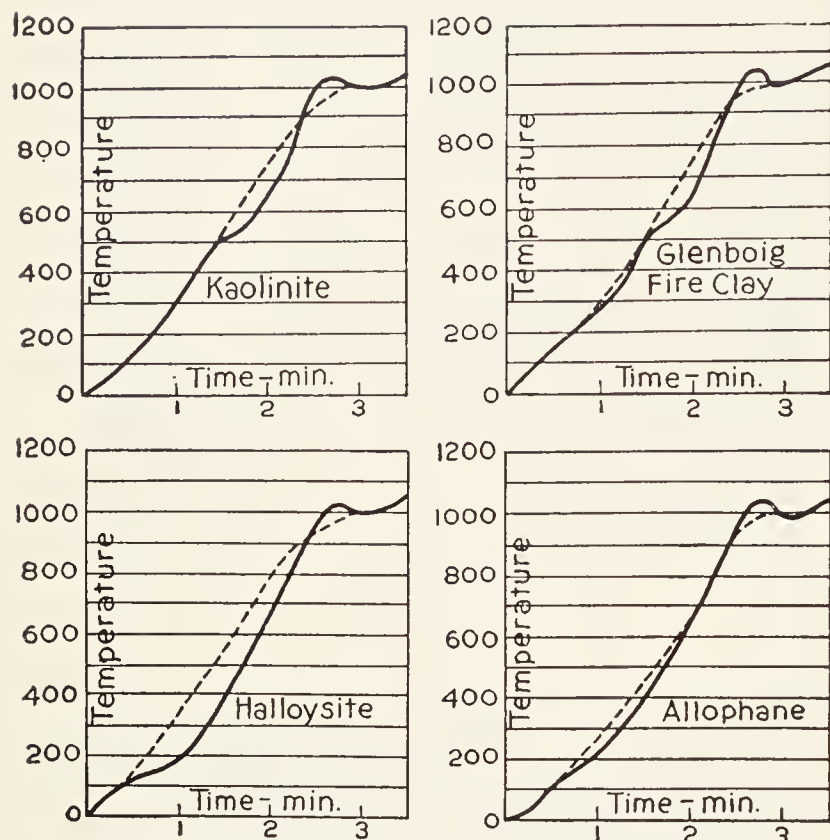


Fig. 7.—Heating curves of air-dried clays (\*).

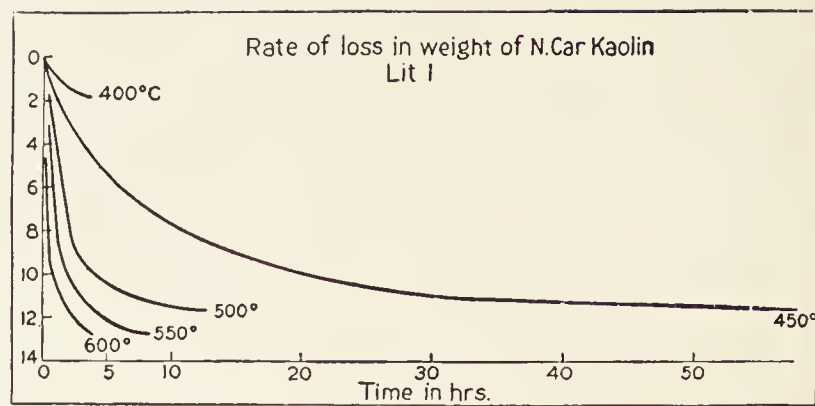


Fig. 9.

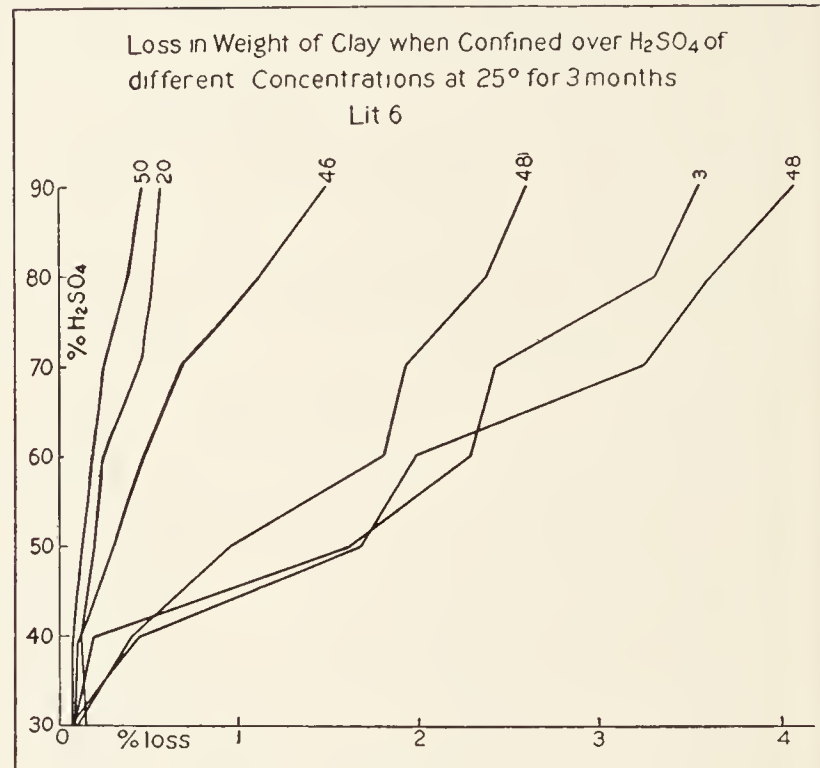


Fig. 10.

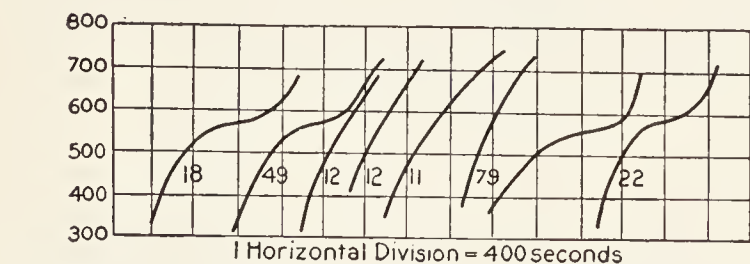
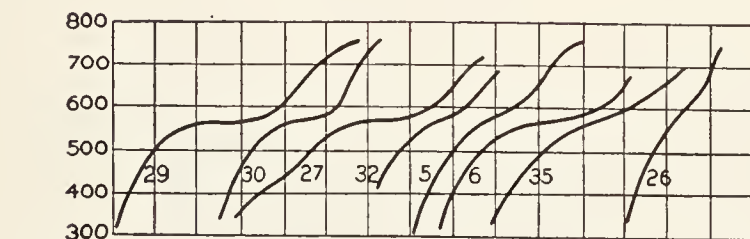


Fig. 8.—Heating curves of various clays (\*).

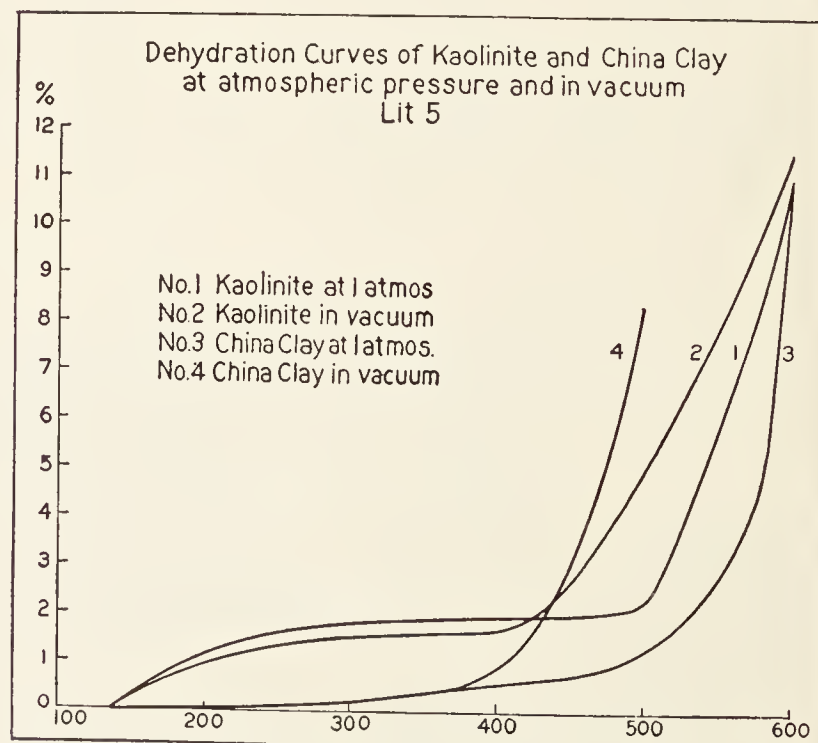


Fig. 11.



## CLAYS

## HEAT ABSORBED AND EVOLVED BY CLAY DURING FIRING AND COOLING, G-CAL/G (7)

For the first two clays the values given are the average results of two independent experiments and the deviations from this average are indicated

Clay type	Loss on ignition, %	Heat absorbed per g per deg. on heating the air-dried (110°) clay over the temperature ranges given				Heat evolved per deg. on cooling the resulting quantity of fired clay			Specific heat of the fired clay cal/g	Dehydration period		
		25-420°	420-900°	900-1200°	25-1200°	1200-900°	900-700°	1200-700°		Pressure rises, deg.	Period of max. pressure, 20 mm, deg.	Pressure falls to 3 mm, deg.
N. C. kaolin.....	14.0	0.49 ±0.07	0.69 ±0.05	0.23 ±0.01	0.50 ±0.035	0.23 ±0.01	0.28 ±0.06	0.24 ±0.05	0.28 ±0.05	25-460	460-570	570-780
A-1 English china.....	12.5	0.42 ±0.01	0.95 ±0.07	0.075 ±0.004	0.55 ±0.07	0.17	0.31	0.20	0.23	25-480	480-540	540-760
Tenn. ball No. 5.....	13.8	0.47	0.53	0.51	0.51	0.20	0.33	0.25	0.29	25-470	470-550	550-830
Laclede-Christy raw flint.....	13.0	0.47	0.68	0.24	0.50	0.17	0.37	0.25	0.29	25-470	470-630	630-850
Average.....		0.46			0.51	0.19	0.32	0.24	0.27			

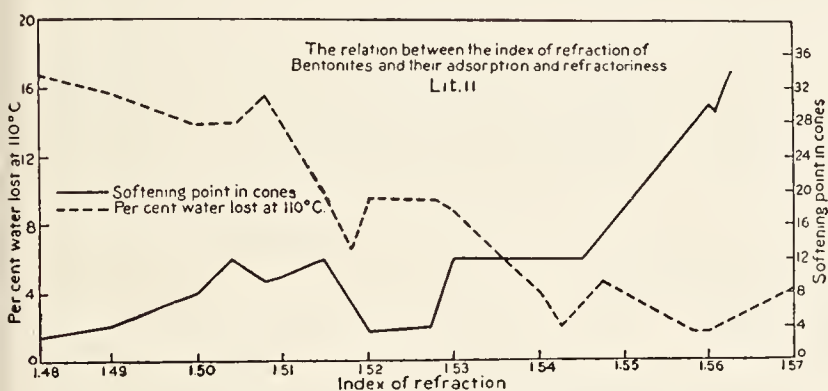


Fig. 12.

## BENTONITE (12), cf. (9)

1. Source of samples tested: 1. Quilchena, British Columbia; 2. Camrose, Alberta; 3. Rosedale, Alberta; 4. Newcastle, Wyo.; 5. Medicine Bow, Wyo.

Sample No.....	1	2	3	4	5
Sp. gr. (pycnometer).....	2.44	2.73	2.72	2.77	2.78
Softening point, cone.....	15		14	11	10
Refractive index.....	1.547		1.558	1.557	
Water absorption, g per g...	1.53	4.15	4.71	4.93	4.95
Loss on ignition, %					
Air drying .....	4.64	3.70	4.28	3.67	
At 450°C.....	4.04*				
At 500°C.....	3.94	3.60*		3.49	
At 550°C.....			4.17*		
At 600°C.....	2.53	2.09		3.43*	
At 700°C.....	1.50	1.14		0.77	
% remaining on 200 mesh sieve.....	2.18	1.58	3.16	0.95	1.21
% passing 200 mesh which settles out of water in 24 hr.....	76.72	10.10	13.14	29.75	11.59
% in suspension in water after 24 hr.....	21.10	88.32	83.70	69.30	87.20

\* Capability of swelling completely destroyed.

## COAGULATING EFFECTS OF REAGENTS UPON BENTONITE

## Water suspensions

Sample No. Reagent	1		3		4	
	10 g in 500 cc H <sub>2</sub> O		2 g in 500 cc H <sub>2</sub> O			
	Re-agent, cc	Precipitate, cc	Re-agent, cc	Precipitate, cc	Re-agent, cc	Precipitate, cc
N HCl.....	4	200	10	225	4	175
½ N NaCl.....	17	200	19	275	18	215
½ N NH <sub>4</sub> Cl.....	14	225	19	250	19	475
½ N BaCl <sub>2</sub> .....	4	165	9	200	14	185
½ N CaCl <sub>2</sub> .....	7	175	5	200	10	180
½ N AlCl <sub>3</sub> .....	2	200	3	215	4	225
N HNO <sub>3</sub> .....	4	195	3	275	4	225
½ N KNO <sub>3</sub> .....	11	200	15	225	10	375
½ N NH <sub>4</sub> NO <sub>3</sub> .....	12	200	19	220	19	485
½ N Ba(NO <sub>3</sub> ) <sub>2</sub> .....	5	200	3	200	4	200
½ N Al(NO <sub>3</sub> ) <sub>3</sub> .....	3	220	2	215	4	225
N H <sub>2</sub> SO <sub>4</sub> .....	3	175	3	175	5	125
½ N Na <sub>2</sub> SO <sub>4</sub> .....	13	200	19	435	18	180
½ N (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> .....	11	230	19	260	30	275
N Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> .....	5	175	4	200	12	175
Satd. CaSO <sub>4</sub> .....	No coagulation up to 50 cc				35	230
Satd. Ca(OH) <sub>2</sub> .....	No coagulation up to 50 cc				36	185
½ N NaOH.....	No coagulation up to 50 cc				28	380
NH <sub>4</sub> OH (0.9 sp. gr.)...	No coagulation up to 100 cc				No coagulation up to 50 cc	
½ N (NH <sub>4</sub> ) <sub>2</sub> CO <sub>3</sub> .....	20	225	40	210	20	215
½ N Na <sub>2</sub> CO <sub>3</sub> .....	No coagulation up to 100 cc		14	300	25	230
CO <sub>2</sub> .....	No coagulation up to 40 cc		No coagulation up to 50 cc		No coagulation	
½ N Na <sub>2</sub> C <sub>2</sub> O <sub>4</sub> .....	No coagulation up to 40 cc		No coagulation up to 50 cc		30	300
CaO.....	g 0.3	150	g 0.5	225	g 0.3	200

## EFFECT OF DILUTION, COAGULATION AND PRECIPITATION

Ten g of sample No. 3 agitated in 350 cc of water and diluted to volume given

Volume in liters	Days	% in suspension after, days				
		1	4	6	10	120
0.5		88.5	87.3	87.3	60.7	
1.0		86.5	74.1	63.4	56.7	33.6
1.5		85.4	71.3	58.3	48.5	
2.0		83.3	60.1	55.0	42.6	34.4
3.0						29.6
4.0						27.6
5.0						25.1

PROPERTIES OF SOME CLAY-LIKE MINERALS OF THE BENTONITE TYPE<sup>(11)</sup>

Source	Index of refraction $n_D$	% water lost at 110°C after air drying	Softening point, cone	% water of plasticity in terms dry wt.	% vol. shrinkage in terms dry vol.	Drying behavior*	Color after firing†
Sanders, Ariz.....	1.48	16.6	3	71.83	69.08	B	Bf
Daggett, Cal.....	1.495-1.505	14.87	8	69.52	94.21	B	Bf
Creede, Colo., No. 1.....	1.505	14.93	12	48.07	59.00	A	Bf
Lovelock, Nev.....	1.505-1.525	10.82	12	78.10	77.26	C	Bf
Newcastle, Wyo.....	1.5175	7.26	9	114.61	161.39	B, E	Bf
Wyoming.....	1.5175-1.5375	9.25	4	99.21	162.73	B, D	Br
Belle Fourche, S. D.....	1.525-1.535	8.79	12	108.07	195.81	B, E	Bf
Creede, Colo., No. 2.....	1.545	1.83	12	37.30	30.16	C	Bf
Enid, Miss.....	1.5475	4.64	14	46.16	73.25	C	Bf
Camden, Ark.....	1.5575	2.19	27	37.30	41.94	C	W
Grossalmerode clay, Germany.....	1.56	1.34	27	22.07	24.21	C	W
Las Vegas, Nev.....	1.56	1.68	30				W
Glass pot clay.....	1.5615	3.02	29	36.08	41.94	C	W
Houston, Tex.....	1.563	0.27	34				W
Enid, Miss.....	1.563	3.25	30	29.75	32.13	C	W
New York.....	1.57	4.55	1	40.97	47.38	C	Bf

\* A = cracks, B = cracks badly, C = does not crack, D = warps, E = becomes very hard on drying. † Bf = buff; Br = brown; W = white.

## LITERATURE

(For key to the periodicals see end of volume)

(1) Brown and Montgomery, 32, No. 21; 13. (2) Houldsworth and Cobb, 82, 22: 111; 23. (3) Howe and Ferguson, 38, 6: 496; 23. (4) Mellor, 82,

16: 73; 17. (5) Mellor and Holderoft, 82, 11: 169; 12. (6) Mellor, Sinclair and Devereux, 82, 21: 104; 22. (7) Navias, 38, 6: 1268; 23. (8) Rieke, 100, 44: 638; 11. (9) Ross and Shannon, 38, 9: 77; 26. (10) Schurecht, 30, No. 233; 20. (11) Schurecht and Donda, 38, 6: 940; 23. (12) Spence, Canada, Mines Branch, Rep. No. 626; 24.

## HEAVY CLAY PRODUCTS

H. G. SCHURECHT

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## 1. CLAY BRICK: SPECIFICATIONS AND PROPERTIES

True specific gravity, 2.4-2.6 (7).

Specific heat, 20-100°C, 0.20-0.25 cal g<sup>-1</sup> deg.<sup>-1</sup>C (1)

	Bulk density, g/cm <sup>3</sup>	Water absorption, %	Compressive strength, kg/cm <sup>2</sup>	Crossbreaking strength, modulus of rupture, kg/cm <sup>2</sup>
Vitrified brick....	2.0-2.2	<5	281 to 351	56 to 84
Hard brick.....	1.9-2.1	5-12	175 to 281	28 to 56
Medium brick*....	1.8-2.0	12-20	105 to 176	21 to 28
Soft brick.....	1.7-1.9	>20	56 to 105	14 to 21
Paving brick†....	1.7-2.2	0.9-8.0	227 to 592	84 to 178

\* Thermal conductivity = 1.6 kg-cal m<sup>-2</sup> hr<sup>-1</sup> (°C, m<sup>-1</sup>)<sup>-1</sup> (7), see also p. 314).

† Rattler loss, 22-26 % (1).

## 2. SAND-LIME BRICK

COMPRESSIVE STRENGTH OF SAND-LIME BRICK WALLS (9)  
Walls 1.83 m long and 2.74 m high

Wall No.	Thickness, cm	Mortar	Compressive strength, kg/cm <sup>2</sup>	
			First crack	Failure
1	21.3	Lime	15.3	22.2
2	33.5	Lime	14.1	20.4
3	21.1	Cement-lime	34.0	47.8
4	33.2	Cement-lime	38.7	39.7
5	21.3	Cement	50.4	67.5
6	32.7	Cement	48.1	59.8



## SAND-LIME BRICK (2)

Dry brick			Effect of wetting. % change in		Effect of freezing. % change in			Effect of fire. % change in		
Compressive strength, kg/cm <sup>2</sup>		Cross-breaking strength, modulus of rupture, kg/cm <sup>2</sup>	Compressive strength	Crossbreaking strength	Compressive strength	Crossbreaking strength	Absorption	Compressive strength		Crossbreaking strength
American method	German method							Dry	Wet	
122-706	66-185	14-83	+17 to -55	+25 to -75	+38 to -55	-22 to -46	+3.8	+53 to -100	-42	-72 to -95

## PER CENT WATER ABSORPTION OF SAND-LIME BRICK (10)

Plant		1 hr	24 hr	Total (boiling 5 hr)
A	Maximum.....	10.6	12.0	17.7
	Minimum.....	4.2	8.2	10.6
	Average of 1000.....	6.8	9.7	13.3
B	Maximum.....	7.9	15.3	18.0
	Minimum.....	4.8	11.3	12.8
	Average of 54.....	6.1	13.2	15.6
C	Maximum.....	6.9	11.9	18.3
	Minimum.....	5.1	10.8	15.9
	Average of 6.....	6.0	11.3	16.9
D	Maximum.....	10.5	14.2	20.6
	Minimum.....	5.4	11.1	15.6
	Average of 56.....	7.1	12.2	17.3
E	Maximum.....	14.4	15.4	22.0
	Minimum.....	5.8	13.2	18.2
	Average of 50.....	8.1	14.1	20.0
F	Maximum.....	16.3	16.7	23.5
	Minimum.....	8.0	13.6	18.8
	Average of 51.....	12.2	14.9	20.7
G	Maximum.....	18.0	18.4	23.8
	Minimum.....	13.1	15.9	21.9
	Average of 8.....	16.1	16.9	22.8
H	Maximum.....	22.4	23.0	31.2
	Minimum.....	8.2	16.8	18.3
	Average of 100.....	16.8	19.5	25.2

## 3. HOLLOW BUILDING TILE (2)

Water absorption, %	Compressive strength, kg/cm <sup>2</sup>						Softening temperature, °C
	Gross area including voids			Net area excluding voids			
	End	Edge	Side	End	Edge	Side	
7.5 to 26	69-373	22-185	49-97	162-798	84-315	162-414	1100-1390

## 4. STONEWARE (7)

Type	True specific gravity	Bulk density, g/cm <sup>3</sup>	Water absorption, %	Compressive strength, kg/cm <sup>2</sup>	Tensile strength, kg/cm <sup>2</sup>	Crossbreaking strength, modulus of rupture, kg/cm <sup>2</sup>	Young's modulus of elasticity	Ball compression strength, kg	Resistance to shock, pendulum impact test, cm kg/cm <sup>2</sup>	Resistance to abrasion, sand blast tests, g/cm <sup>2</sup>	Hardness, scleroscope	Linear coef. of expansion, per °C	Specific heat, 20°-100°C, g-cal g <sup>-1</sup> per °C	Softening cone	Heat conductivity, kg-cal m <sup>-2</sup> hr <sup>-1</sup> (°C, m <sup>-1</sup> ) <sup>-1</sup>	Dielectric constant
Common	2.44-2.65	2.06-2.37	0.03-5.1	3248-5833	63-116	234-416	4189-6850	476-1044	1.26-1.90	3.0-9.9	39-62	4.1 × 10 <sup>-6</sup> to 4.9 × 10 <sup>-6</sup>	0.185-0.191	17-29	0.95-1.35	
Chemical	2.45-2.53	2.28-2.32	0.13-1.80	5816	163-178	416-980	5087-15130	792-980	1.70-2.40	2.4-3.9	55-64	4.9 × 10 <sup>-6</sup> to 5.7 × 10 <sup>-6</sup>		17-30	1.00-1.25	5.17

## 5. SANITARY BODIES (4)

	Water absorption, %	Crossbreaking strength, modulus of rupture
Fire clay ware.....	16 to 18	70 to 92 kg/cm <sup>2</sup>
Vitreous ware.....	2 to 3	184 to 230 kg/cm <sup>2</sup>

## 6. FLOOR AND WALL TILE (6)

*Water Absorption.*—Vitreous, 0 to 2%. Semi-vitreous, 2 to 10%. Plain unglazed, 10%.

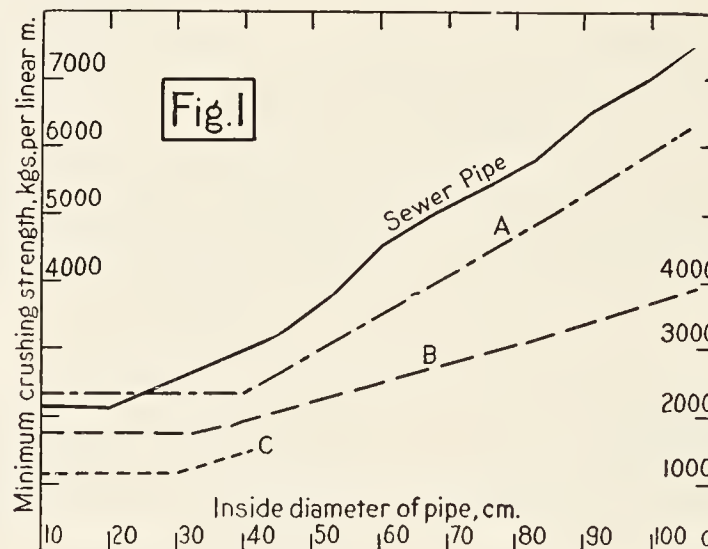
## 7. DRAIN TILE

A. S. T. M. Specifications (1).

*Types.*—A, Extra quality, H<sub>2</sub>O absorption, 11%; B, Standard, H<sub>2</sub>O absorption, 13%; C, Farm, H<sub>2</sub>O absorption, 14%. For compressive strength, see Fig 1.

## 8. SEWER PIPE

A. S. T. M. specifications for vitrified salt-glazed sewer pipe (1). H<sub>2</sub>O absorption, 8%. For crushing strength, see Fig. 1.



## 9. TERRA COTTA BODIES (5)

Water absorption, 10 to 19 %. Crossbreaking strength, modulus of rupture, 105 to 180 kg/cm<sup>2</sup>. Linear coefficient of expansion, 17° to 100°C,  $(3.7 \text{ to } 6.0) \times 10^{-6}$  per °C.

## 10. CRUSHING STRENGTH OF MASONRY WITH DIFFERENT MORTARS (8)

Brick employed: 23 × 11 × 5.5 cm (nine different types). a, Cement mortar, 1:3. b, Lime mortar. c, Mortar mixtures. a + b (1:1).

Strength of one meter cubes of masonry in kilograms

a	b	c
1929	1959	1977
1908	1940	1955
1852	1885	1903
1772	1812	1851
1722	1780	1829
1713	1771	1823
1715	1770	1824
1709	1767	1821
1709	1765	1819

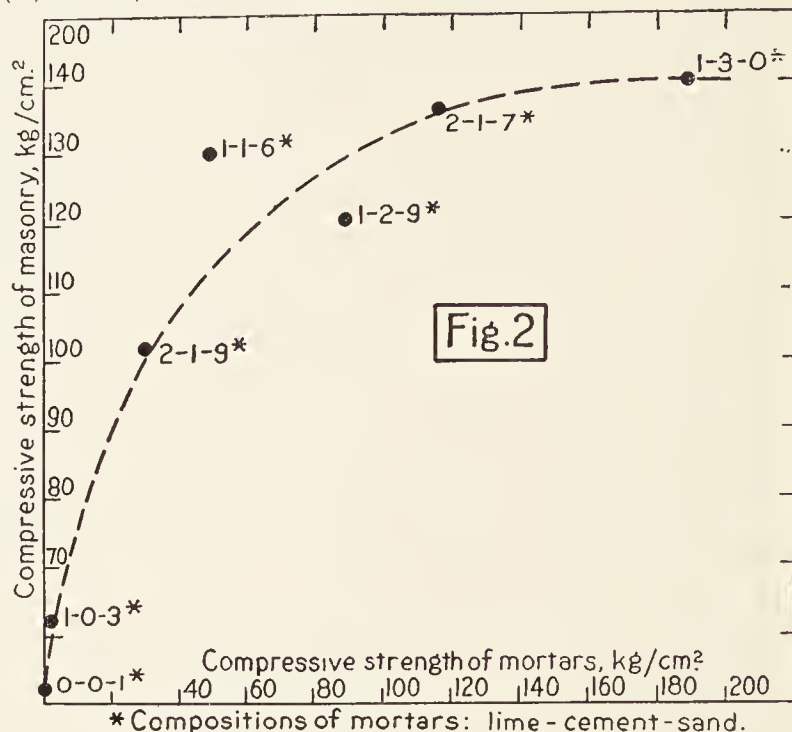
According to Kreuger (11) the compressive strength of a brick pier is ca.  $0.22 \times$  the compressive strength of the brick used in its construction. The corresponding relation to the compressive strength of the mortar used is shown in Fig. 2.

## LITERATURE

(For a key to the periodicals see end of volume)

(1) American Society for Testing Materials, Specifications. (2) Emley, 32, No. 85: 35; 17. (3) Foster, 38, 7: 189; 24. (4) Fuller, Bureau of Standards, O. (5) Fuller and Merrit, Bureau of Standards, O. (6) Pence, 81, 17: 484; 15. (7) Singer, *Keramik* (Braunschweig, Vieweg und Sohn), 470; 23. (8) Svenson, 314, 36: 341; 12. (9) Whittemore and Stang, 32, No. 276: 65; 25.

(10) Johnson, Bureau of Standards, O. (11) Kreuger, 314, 40: 597; 16.



## PORCELAIN AND WHITEWARE

I. Electrical porcelain. II. Laboratory porcelain and white ware. Owing to the overlapping of these two classes a certain amount of duplication occurs in the tables but for the complete data both sections should be consulted.

I. Porcelaines électriques. II. Porcelaines et faïences de laboratoire. Etant donné le chevauchement de ces deux classes, il y a un certain nombre de répétitions dans les tables; pour avoir des données complètes, les deux sections doivent être consultées.

I. Elektro-Porzellan. II. Laboratoriums Porzellane und Steingut. Da beide Gattungen in engerr Beziehung stehen, ist eine gewisse Wiederholung in den Tafeln vorhanden. Doch sollen für vollständige Daten beide Abschnitte herangezogen werden.

I. Porcellane elettriche. II. Porcellane di laboratorio e grès ceramico. Per la stretta relazione tra le due categorie, vi è qualche ripetizione nelle tabelle. Per avere dati completi bisogna però consultare entrambi i capitoli.

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## INHALTSVERZEICHNIS

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## I. ELECTRICAL PORCELAIN

FRANK H. RIDDLE<sup>1</sup>

## Classification of Porcelains Based on Their Use

## I. Normal porcelains.

(A) Low tension porcelain, porosity, 1 %.

Dry or wet process used under 5000 volts. Flint, clay, feldspar porcelain.

(B) High tension porcelain, porosity, 0 %.

Wet process used above 5000 volts. Flint, clay, feldspar porcelains.

## II. Special porcelains.

(C) Spark plug core porcelains, porosity, 0 %.

Usually free from free quartz which has objectionable expansion and alkalis which have an injurious effect upon the insulation at increased temperatures.

(D) Heating element porcelains, porosity, 1 %.

Usually containing over 50 % magnesia compounds.

(E) Thermocouple porcelains for protection.

High in alumina and free from free quartz.

Practically nothing is available in the literature regarding low tension porcelain or heating element porcelain.

Fig. 1

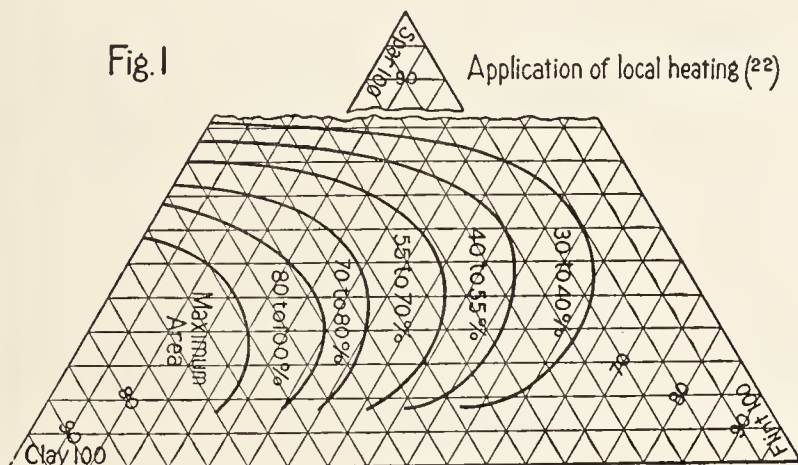
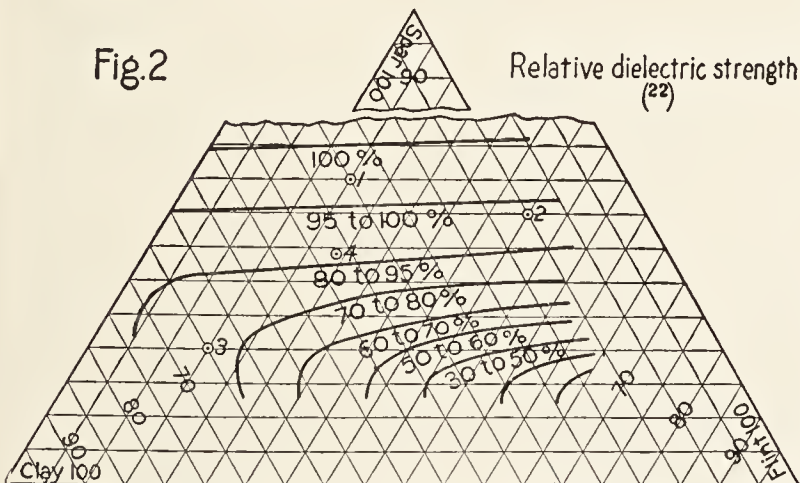


Fig. 2



## Chemical Composition of Fired Body and Batch Composition of Raw Body

Typical compositions of the possible range of raw bodies are shown in Figs. 1, 2, 3 and 4. These figures can be used only as a general guide, since they do not portray the effects of the different varieties of clay, feldspar and flint, or the methods of grinding, etc.

<sup>1</sup> Grateful acknowledgments are due to Dr. Joseph A. Jeffery for the privilege of carrying out considerable research work in the research laboratories of the Champion Porcelain Company; to Messrs. H. F. Royal, E. K. Bibb, Walter Schmidt, and to Miss Chenoweth and other members of the staff for valuable aid in the assembling and classification of data; and to Messrs. L. E. Barringer and F. W. Peek, Jr., of the General Electric Company, for much valuable information.

The actual compositions of some of the bodies whose properties are listed in the following pages are shown below, together with the reference numbers by which they are identified in the tables.

## BODY COMPOSITIONS

Calcines, wt. % (Chamotte, Aufbereitungsstoffe, Materiali digrassanti)

	Cone	MgCO <sub>3</sub>	Kaolin	Flint	Al <sub>2</sub> O <sub>3</sub>	Boric acid
(A)	12	14.40	44.30	41.30		
(B)	13	18.20	56.00	25.80		
(C)	18		70.20		27.80	2.0
(D)	18		55.80		44.20	
(E)		23.85	76.15			

Fig. 3

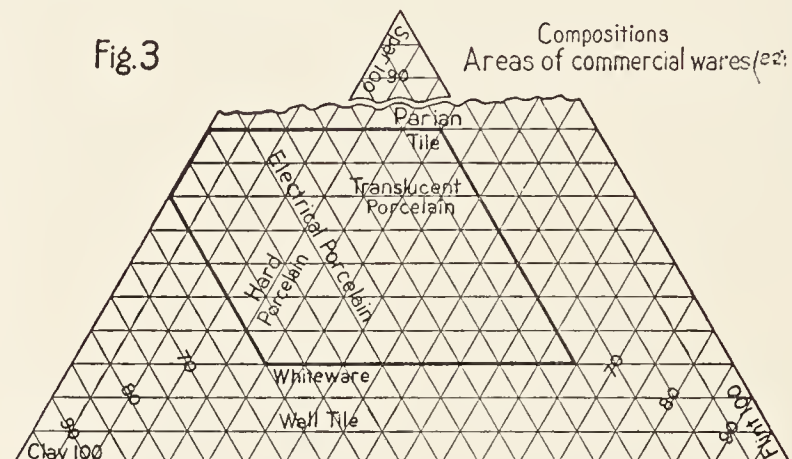
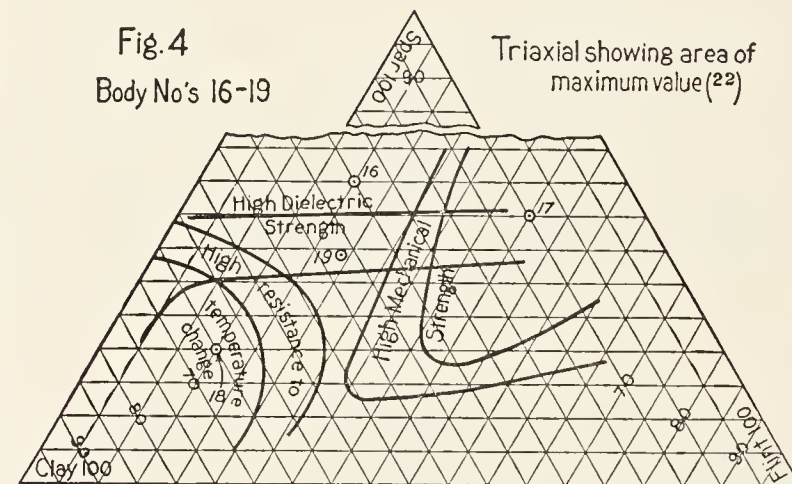


Fig. 4

Body No's 16-19

Triaxial showing area of maximum value (22)



Bodies, wt. % (Matières céramiques, Keramische Massen, Paste ceramiche)

Ref. No.	1	2	3	4	5	6	7	8	9	10	11
Clay.....	35	35	45	45	50	50	55	55	55	55	65
Flint.....	40	30	30	20	25	15	10	22.5	15	5	10
Feldspar.....	25	35	25	35	25	35	35	22.5	30	40	25

Ref. No.	15	16	17	18	19	20	21	22	23	24	25
Clay.....	40	35	15	65	42	*	22	30.2	40	50.0	50.0
Sillimanite.....											30.0
Flint.....	15	20	45	15	24					32.5	2.0
Feldspar.....	45	45	40	20	34					16.0	16.0
Al <sub>2</sub> O <sub>3</sub> .....							18	12.6			
Whiting.....										1.5	1.5
Calcine.....							60D	57C	{ 20B 40C		
Cone.....	10 to 14		18		32		30	17	11	11	

\* Natural sillimanite (andalusite) with clay bond.

Ref. No.	26	27	28	29	30	31	32	33	34	35
Clay.....	50.0	50.0	50.0	50.0	45	50	55.0	60	50	45
Calcined clay.....	20.0	8.5	35.0	5.0						35
Flint.....	18.5				27	26	15.0	10	30	
Sillimanite.....		30.0		30.0						
Feldspar.....	10.0	10.0	13.5	13.5	28	24	28.5	30	8	
Whiting.....	1.5	1.5	1.5	1.5			1.5			
Calcine.....									12E	20A

Ref. No.	36	37	38	39	40	41	42	Range %*	Standard %†
Clay.....	50	50	46	46	50	50	50	40-55	50
Feldspar...	25	16	26	21	20	20	20	25-30	30
Flint.....	25	34	28	33	30	30	30	15-25	20

\* For satisfactory bodies (20).

† A standard composition (20).

## CHEMICAL COMPOSITION

Ref. No.	1	2	3	4	5	6	7	24*	25*	26*	27*	28*	29*
SiO <sub>2</sub> .....	74.08	70.81	69.23	65.96	66.78	63.51	61.08	72.51	52.10	64.59	49.81	55.93	50.38
Al <sub>2</sub> O <sub>3</sub> .....	15.63	17.47	18.50	20.34	19.95	21.79	23.22	22.60	42.24	30.86	45.05	38.40	44.10
TiO <sub>2</sub> .....	0.40	0.40	0.56	0.56	0.64	0.64	0.72	0.16	0.12	0.15	0.24	0.19	0.23
Fe <sub>2</sub> O <sub>3</sub> .....	0.48	0.50	0.59	0.61	0.64	0.66	0.71	0.14	0.59	0.53	0.64	0.66	0.63
CaO.....	0.25	0.32	0.27	0.34	0.28	0.35	0.36	1.05	1.10	1.07	1.11	1.13	1.13
MgO.....	0.22	0.25	0.26	0.29	0.28	0.31	0.33	0.18	0.26	0.22	0.28	0.28	0.27
K <sub>2</sub> O.....	2.72	3.67	2.79	3.74	2.83	3.78	3.82	1.98	2.18	1.58	1.67	2.07	1.98
Na <sub>2</sub> O.....	1.39	1.75	1.57	1.93	1.66	2.02	2.11	1.08	1.31	1.05	1.20	1.34	1.28
Ignition loss.....	4.83	4.83	6.24	6.24	6.94	6.94	7.65						

\* Fired body.

## Petrographic Character of Insulator Porcelains

A comparative petrographic study of a number of insulator porcelains of American, French and German manufacture leads to the following conclusion.

A good porcelain insulator made from clay, feldspar and flint should consist largely of a glassy matrix with embedded crystals of quartz and mullite (3Al<sub>2</sub>O<sub>3</sub>·2SiO<sub>2</sub>) evenly distributed throughout. The quartz should not exceed 20 to 25 %, preferably less, and the fragments should have rounded edges and corners, as indicating partial solution by the feldspar glassy matrix. The average grain size of the quartz should not exceed 0.03 to 0.04 mm diameter, and the particles should be evenly distributed. No clay or partially decomposed clay particles should be present. The crystals of mullite should be abundant, well-formed, evenly distributed, and should not exceed *ca.* 0.01 mm length by 0.002 mm thickness.

Owing to the very close resemblance between mullite and sillimanite crystals, the following crystallographic characterization is given (9, 70).

	Mullite 3Al <sub>2</sub> O <sub>3</sub> ·2SiO <sub>2</sub>	Sillimanite Al <sub>2</sub> O <sub>3</sub> ·SiO <sub>2</sub>
Crystal system.....	Orthorhombic	Orthorhombic
Prism angle, 110 $\wedge$ 110.	89° 13'	88° 15'
Cleavage.....	010	010
Optic orientation.....	$\hat{c} = \gamma$ and $a = \alpha$	$\hat{c} = \gamma$ and $a = \alpha$
Refractive indices {	$\gamma$ .. 1.654	1.677
	$\alpha$ .. 1.642	1.657
Axial angle, 2V.....	+45°, -50°	+25°, -30°

## BULK DENSITY, SPECIFIC GRAVITY AND POROSITY

## 1. Typical electrical porcelains for high-tension work

Specific gravity	Bulk density, g/cm <sup>3</sup>	Open-pore porosity, %	Total porosity, %	Type	Lit.
2.3-2.5				Hermesdorf	(53)
2.46	2.317		5.8	Berlin hard	
2.45	2.233	1.80	8.9	DTS sill. Z54	(53)
2.45	2.276	0.19	7.3	DTS sill. Z55	(53)
	2.24-2.35			In general	(4)
		0.01		Elec. average of 8	(63)
2.46	2.25		7.7	Elec. Ref. No. 15	(48)

## 2. Special spark plug and vitrified pyrometer porcelains (48)

2.77	2.54	0.00	8.4	"Sill." spark plug 6012, Ref. No. 20
3.03	2.83	0.00	6.8	Artificial mullite, Ref. No. 21
2.89	2.72	0.00	5.7	Artificial mullite, Ref. No. 22

## Coefficient of Cubical Compressibility

$\frac{10^6 dV}{VdP} = 1.4$  to 1.8 per atm. The lower figure is for highly siliceous, and the latter for highly feldspathic, porcelains (56).

## TENSILE STRENGTH (DEF. 4)

kg/cm <sup>2</sup>	Type	Cross section*	Lit.
843.6	Sill. (mullite).....	0.864 cm <sup>2</sup>	(38)
684	Sill. (mullite).....	0.864 cm <sup>2</sup>	(39)
519	Insulator.....	3.226 cm <sup>2</sup>	(20)
514	Sill. (mullite).....	6.45 cm <sup>2</sup>	(39)
421.8	Insulator average of 7†.....	0.864 cm <sup>2</sup>	(12)
360	Hermesdorf 103.....	3.14 cm <sup>2</sup>	(53)
320	Berlin hard.....	3.14 cm <sup>2</sup>	(53)
261	Rosenthal H.....	7½ × 2 cm	(56)
240	Various.....	7½ × 2 cm	(15)
178	DTS sill. Z54.....	0.314 cm <sup>2</sup>	(53)
163	DTS sill. Z55.....	7½ × 2 cm	(53)
140-260	Various.....	7½ × 2 cm	
130-200	Hermesdorf.....		(42)
122	Marquardt.....	7½ × 2 cm	(53)
98	Insulator.....	7½ × 2 cm	(45)

\* The area of the cross section of the test piece is important, see Fig. 5.

† Batch weights and chemical compositions of these bodies are shown under Ref. Nos. 1-7.

## ILLUSTRATING THE INFLUENCE OF THE GLAZE

All pieces made of the same body and all burned together (40); see also especially (21.1)

kg/cm <sup>2</sup>	623	720	642	305
Type.....	No glaze	Best glaze	Good glaze	Crazed glaze

Compare the tensile and crushing strengths of American and German bodies. The German bodies have a greater crushing strength, the American bodies a greater tensile strength.

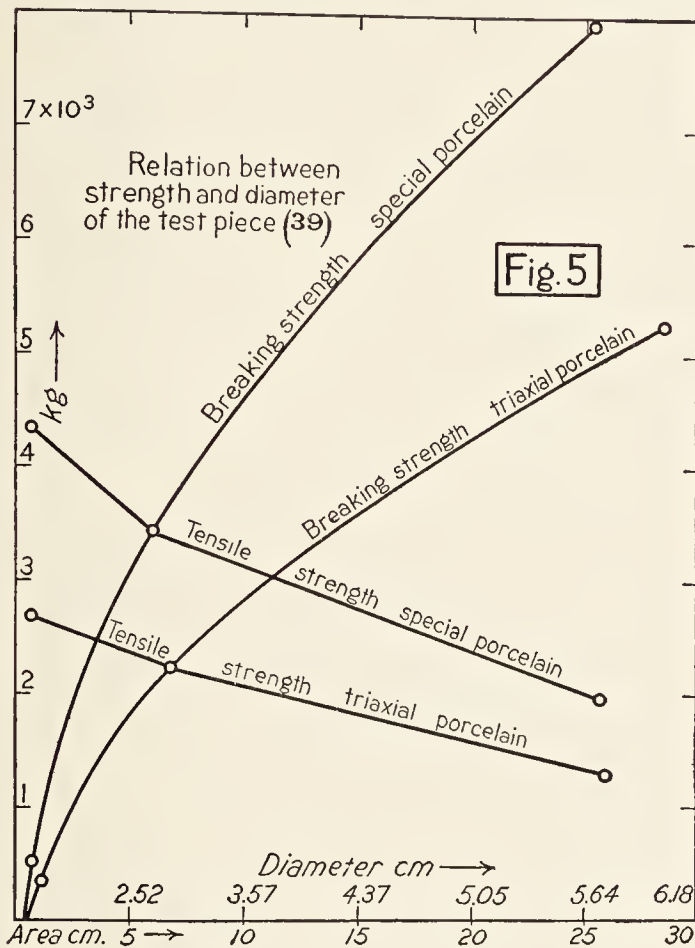


## MODULUS OF RUPTURE\*

kg/cm <sup>2</sup>	Type	Lit.	kg/cm <sup>2</sup>	Type	Lit.
590	Insulator.....	(45)	500		(49)
580	DTS sill. Z55..	(53)	490	Hermesdorf.....	(46)
595-469	Average of 7 elec.†.....	(38)	416	DTS sill. Z54..	(53)
560-420		(19)	246	Marquardt....	(53)
540	Insulator H...	(46)			

\* Extruded cyl. pieces 120 mm long, and 16 mm diam., burned hanging in vertical position and sawed to length. Supported on steel knife edges 10 cm apart and loaded centrally, 1 kg per sec.

† For compositions see Ref. Nos. 1-7, inclusive. For effect of glaze see (21.1).



CRUSHING STRENGTH  
Unit is 1000 kg/cm<sup>2</sup>

Strength	Type	Remarks	Lit.
5.8*	DTS sill.....		(53)
>5.6*	Hermesdorf.....		(53)
>5.0*	Rosenthal H.....	2.11 cm <sup>2</sup>	(46)
4.8-4.2	Hermesdorf.....	16 × 16 mm	(56)
4.5	Insulator.....		(45)
4.2	Berlin hard.....	2.5 cm cubes	(42)
4.0	Sill. average of 7.....	4.90 cm <sup>2</sup>	(39)
4.0†	Insulator.....		(56)
2.5†	Insulator average of 3.....	2.54 cm diam.	(38)
1.6-1.8‡		6 × 3 cm	(8)
1.0	Marquardt.....		(53)
4.2-3.1§	Elec. various.....	Cyl. 3.14 cm <sup>2</sup>	(44)

\* The higher values are probably due to the use of cylindrical test pieces instead of square ones. In 1920 the German committee appointed to arrange standard tests decided on a test piece 16 × 16 mm diameter. According to Demuth (15) test pieces smaller than 50 × 50 mm are too small and the high results obtained are misleading.

† For compositions see Ref. Nos. 4, 5 and 7.

‡ The higher value is for glazed, the lower for unglazed.

§ For compositions see Ref. Nos. 8-11.

## CRUSHING STRENGTH BETWEEN SPHERES\* (53)

kg	982	792	748
Type.....	DTS sill. Z55	DTS sill. Z54	Marquardt

\* The Gary press (43) used for this test holds a piece 1 cm thick and 10 cm wide between steel balls 31.7 mm in diameter, through which the pressure is applied. Results calculated to correspond to a disc 1 mm thick.

## MODULUS OF ELASTICITY (DEF. 10)

The unit is 1000 kg/mm<sup>2</sup>

Modulus	Type	Remarks	Lit.
10.6	"G. E.".....	Bending	(10)
10.2	"G. E.".....	Tensile (v. Fig. 1)	(10)
8.9	Marquardt.....	Bending	(53)
8.7	O. S. Univ.....	Tensile	(10)
8.4*	Rosenthal.....	Bending	(56)
8.3	Berlin hard.....	Bending average of 72	(59)
8.0-7.0	Hermesdorf.....		(53)
7.8	Rosenthal.....		(53)
7.8	Insulator.....		(53)
7.1-5.4	Hermesdorf 104.....	End support	(19)
7.0	Average.....		(4)
7.0-5.0	Hermesdorf 1915.....		(42)
6.5	DTS sill. Z55.....		(53)
5.1	DTS sill. Z54.....		(53)
8.9	Westinghouse.....	Bending 12.7 mm rod	(20)
6.3	Hermesdorf 1921.....	End support	(56)
5.2	Westinghouse.....	Bending 19 mm rod	(20)

\* With varying loads this value varied from 8.4 to 17.9 with the same test pieces and under uniform conditions. Tests made by Steger's method (59).

The modulus is dependent more upon the conditions of manufacture than upon chemical composition. It is substantially the same for tension and compression. For G. E. porcelain Boyd (10) found the following relations:  $D = 0.133L$  for compression;  $D = 0.133L$  for bending;  $D = 0.143L$  for tension; where  $D$  = deformation in 0.00001ths, and  $L$  = load in kg-cm<sup>-2</sup>.

## MODULUS OF ELASTICITY IN SHEAR (DEF. 11)

kg/cm <sup>2</sup>	Type	Lit.	kg/cm <sup>2</sup>	Type	Lit.
600-480	Hermesdorf 103	(53)	481	Insulator 101 G	(46)
500	Rosenthal H	(46)	430	Sege 6833*	(46)
500	Rosenthal laboratory porcelain	(46)	323	DTS sill. Z54	(53)

\* Square test piece.

## FIXED IMPACT AND BENDING SHOCK (DEF. 16)\*

cm-k-g-wt. cm <sup>2</sup>	Rosenthal porcelains	Lit.	cm-k-g-wt. cm <sup>2</sup>	Type	Lit.
2.4	Spec. 6412.....	(56)	1.9	Hermesdorf	(53)
1.61	Spec. 6048.....	(45)	1.8	DTS sill. Z54	(53)
1.38	Spec. 6048.....	(56)	1.7	DTS sill. Z55	(53)
1.23	Laboratory.....	(56)			
1.00	Sege 6833.....	(56)			
0.95	Insulator H.....	(56)			
0.90	Insulator G.....	(56)			
0.08	Hard 6292.....	(56)			

\* Pendulum-hammer method. 16 × 16 × 120 mm bar, 100 mm span, 10 cm-k-g-wt. blow (53).

## SUCCESSIVE INCREASING IMPACT SHOCKS\*

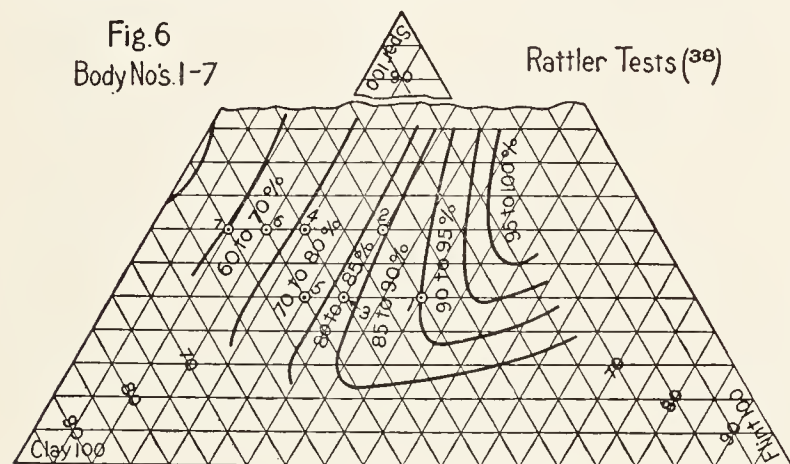
cm-kg-wt. cm <sup>3</sup>	Rosenthal porcelain	Lit.
146	Stoneware 6412.....	(56)
117	Laboratory.....	(56)
105	Insulator H.....	(56)
98	Insulator G.....	(56)
69	Sege 6833.....	(56)
10	Marquardt.....	(53)

\* Marten's method consists in letting a weight drop from successively increasing heights upon a disc-shaped test piece until rupture occurs. The effect is measured in cm-kg-wt. per unit volume of the test piece. Result independent of size of test piece.

## RESISTANCE TO ABRASION

Gary sand blast test, 2 min at 3 atm

Type	Loss in cm <sup>3</sup>	Lit.
Insulator G.....	2.4	(46)
Rosenthal (Selb.) H.....	3.3	(46)
Marquardt 1.....	10.3	(14)
DTS sill. Z54.....	2.5	(53)
DTS sill. Z55.....	3.9	(53)
Sege hard 6412.....	1.7	(46)



## TOUGHNESS AND HARDNESS BY THE "RATTLER" TEST\*

Per cent loss of weight by rattler test (38)

15 min	30 min	3 hr	Type
2.2	3.5	10.6	1, Fig. 6
3.2	5.2	14.4	2, Fig. 6
4.4	8.8	21.6	3, Fig. 6
8.0	14.5	27.4	4, Fig. 6
5.1	9.6	23.6	5, Fig. 6
7.8	12.2	29.6	6, Fig. 6
10.2	14.2	33.6	7, Fig. 6

\* The 15 min test is an indication of the toughness or resistance to chipping. The 3 hr test is an indication of hardness after edges and corners are gone. Ratio: Marquardt to DTS sill. Z54, is 2.6, time not stated (53).

With a constant clay content the higher spar and lower flint body is invariably weaker. Increase in clay and decrease in flint decreases strength. The compositions of the bodies are plotted on the triaxial diagram, Fig. 6. Note the relation between loss in wt. and body composition.

Tests were carried out under the following conditions: 13 test pieces  $2.25 \times 2.25 \times 5.0$  cm with square edges. Tested in porcelain jar mills 24.75 cm diam.  $\times$  33 cm long inside rotating at 40 r.p.m. Besides the test pieces there were 61 pebbles weighing 10 kg. The test pieces were removed and weighed at the time specified.

## SOFTENING POINT

Cone	Type	Lit.
20	Ref. No. 15	(48)
18	Ref. No. 16	(48)
15 down	Raw { Ref. No. 17 } { Ref. No. 18 }	(48)
31		(48)
20 down	Ref. No. 19	(48)
26	American	Typical insulator
27	French	
31 tipped	German	
32 down	"Sill." spark plug	(48)

Softening point varies with size and shape of test piece, time of heating, etc.

## COEFFICIENT OF THERMAL EXPANSION

$\frac{10^6 \Delta l}{l \Delta t}$	Type	Range, °C	Lit.
4.25	Hermsdorf.....		(53)
4.00	G. E.....		(2)
5.42	Lock insulator ('09).....	20-101	(65)
5.35		19-243	(65)
3.79	High tension.....	16	(55)
3.79	Rosenthal.....	20-100	(56)
3.80	Sege 6833.....	20-100	(53)
6.66	Elec. 1 EL.....	20-500	(11)
4.36	Elec. 1 EL.....	20-400	
4.85	Elec. 2 EL.....	400-600	(11)
5.2	Marquardt.....		(53)
2.7	Fired to Cone 26 ( $\text{Al}_2\text{O}_3 \cdot \text{SiO}_2$ ).....	25-200	(37)
3.9		200-400	(37)
3.3		25-400	(37)
3.36		30-200	(6)
4.19	"Sill." spark plug; Ref. No. 23.....	200-400	(6)
4.78		400-500	(6)
3.81		30-400	(6)
5.3		25-400	(37)
3.5	Ref. No. 25.....	25-400	(37)
5.5	Ref. No. 26.....	25-400	(37)
3.5	Ref. No. 27.....	25-400	(37)
3.3	Ref. No. 28.....	25-400	(37)
3.7	Ref. No. 29.....	25-400	(37)
6.17	High tension.....	?	(20)
5.27	High tension.....	?	(20)
3.43	$\text{Al}_2\text{O}_3 \cdot \text{SiO}_2$ vitrified at cone 32.....	119.0	(67)
3.78		230.5	
4.01		317.7	
4.16		392.7	
4.40	$3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$ vitrified at cone 32....	512.7	(67)
3.63		117.0	
3.95		216.5	
4.18		304.3	
4.36	Average of five refractory porcelains	383.3	(68)
4.62		492.5	
2.37		114.2	
3.07		234.7	
3.69		357.2	(68)
4.00		482.6	
4.21		601.7	
4.51		724.1	
4.84		844.2	

## Resistance to Thermal Shock

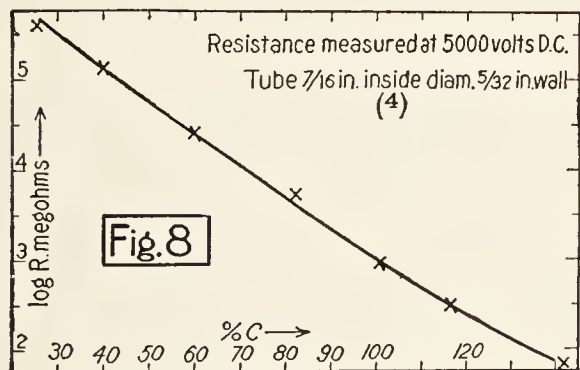
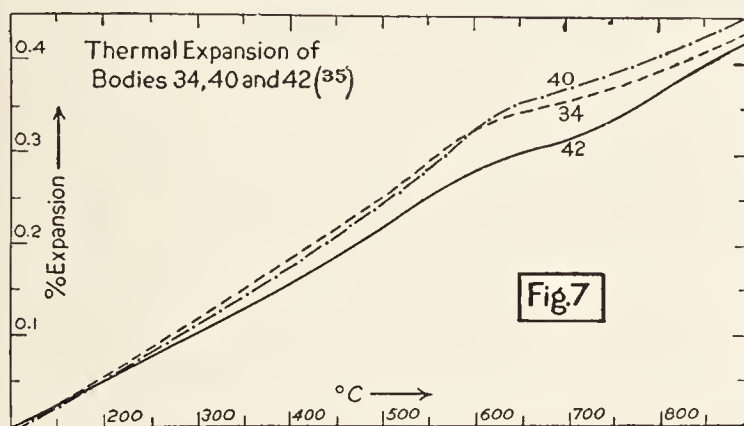
The recorded data are not comparable owing to lack of standard methods v. (8, 54, 66, 29). The relative heat shock strengths of a series of electrical porcelains covering the whole range of com-



positions is shown in Fig 4 (22). Substitution of  $ZrO_2$  for  $SiO_2$  improves the resistance to thermal shock (60, 69). "Sillimanite" (mullite) porcelains have a greater resistance than ordinary kinds.

## VOLUME RESISTIVITY

Temp., °C	Sp. resist. Megohm-cm	Type	Lit.
613-900	0.068-1.098	Berlin	(33)
727	0.007		(17)
727-1292	0.100-0.0034		(33)
20	$129 \times 10^6$	Stand. G. E. plastic	(16)
189	$0.385 \times 10^6$		(16)
300	19		(2)
350	9		(2)
400	3.5		(2)
500	1.5		(2)
600	0.8		(2)

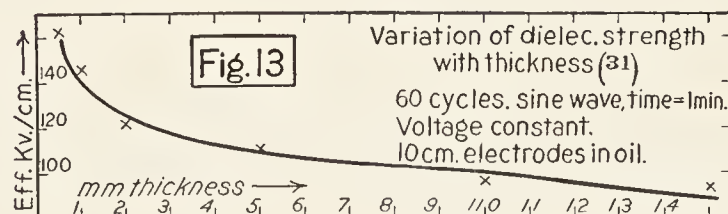
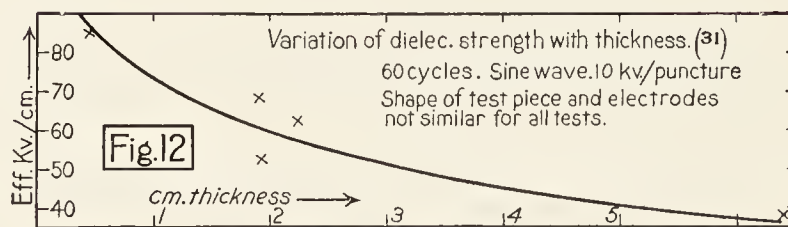
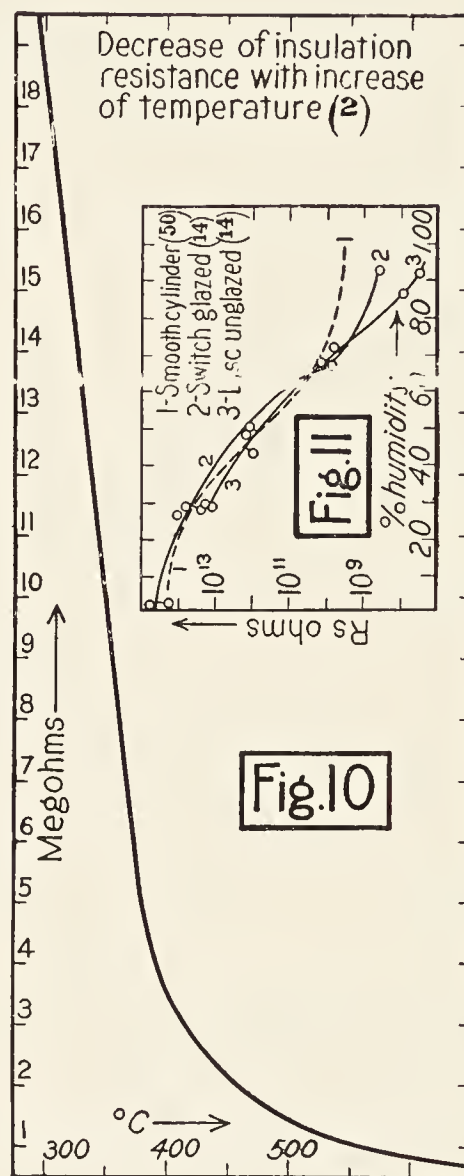
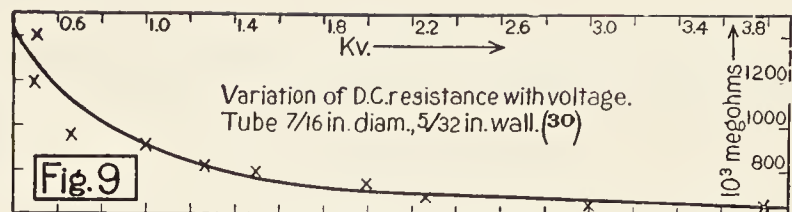


Some experimenters compare porcelains by finding the temperature at which the resistance is equal to one megohm-cm. They have termed this temperature the "effective temperature,"  $T_E$ ; see also Figs. 8, 9 and 10.

$T_E$ , °C	Composition	Cone	Lit.
370	Ref. No. 30.....	14	(52)
358	Ref. No. 31.....	14	(52)
390	Ref. No. 32.....	12	(52)
400	Ref. No. 33.....	10	(6)
590	Ref. No. 34.....	15	(6)
610	Ref. No. 35.....	16	(6)
690	Ref. No. 23.....	16	(6)

## SURFACE RESISTIVITY

Varies enormously with humidity of the atmosphere and with the nature of the surface film. For variation of the resistivity of a clean surface with atmospheric humidity, see Fig. 11.



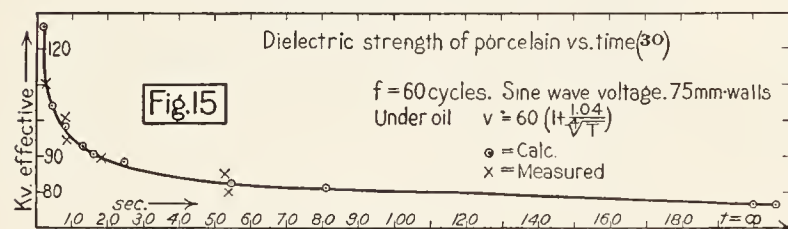
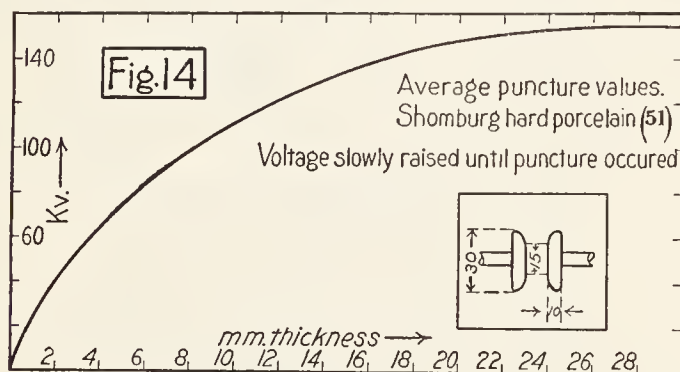
## DIELECTRIC CONSTANT

6.15 for a G. E. wet process porcelain at  $10^5$  cycles,  $25^\circ\text{C}$  and 60% relative humidity (2); see further p. 80.

## DIELECTRIC STRENGTH

1. Shape of the electrodes not given. Voltage increased 1 kv/2 sec, starting at 20 kv under oil

Volts per mm	Type	Remarks	Lit.
10 000	Hermendorf.....	5 mm thick test porcelain	(19)
9 000	Hermendorf.....	10 mm thick test porcelain	(19)
$\frac{1}{2}$ of above	.....	At $275^\circ\text{C}$	(19)
16 000	Royal Berlin.....	$2\frac{1}{2}$ mm thick	(42)
17 200	Ref. No. 36.....	5 mm discs. Cone 15	(61)
12 500	Ref. No. 37.....		(61)
18 100	Ref. No. 38.....		(61)
20 300	Ref. No. 39.....		(61)
27 400	Ref. No. 40.....		(61)
18 300	Ref. No. 41.....		(61)
28 700	Ref. No. 42.....		(61)



2.  $25^\circ\text{C}$  under oil, 12.7 mm electrodes with rounded edges, voltage increased 1 kv per sec

9 100	Ref. No. 16.....	Test piece 6.35 mm to 9.14 mm. 60 cycle sine-wave voltage	(3)
9 400	Ref. No. 17.....		(3)
10 600	Ref. No. 18.....		(3)
8 400	Ref. No. 19.....		(3)

According to Peek (31) the puncture tests on solid insulators vary greatly between different samples of the same material, shape and area of the electrodes, time of application of voltage, etc.; see Figs. 12-16.

## DIELECTRIC LOSSES

For variation of dielectric losses and power factor with frequency, see (25).

## FLASH-OVER VOLTAGE

Effect of humidity, Fig. 18.

Effect of length of test piece, Fig. 17.

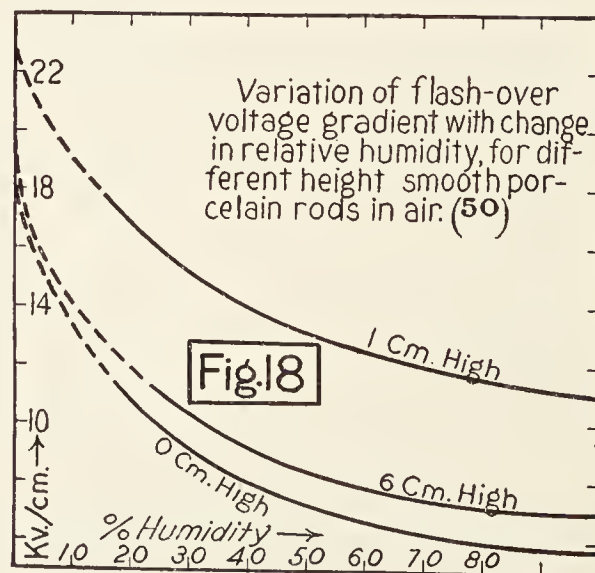
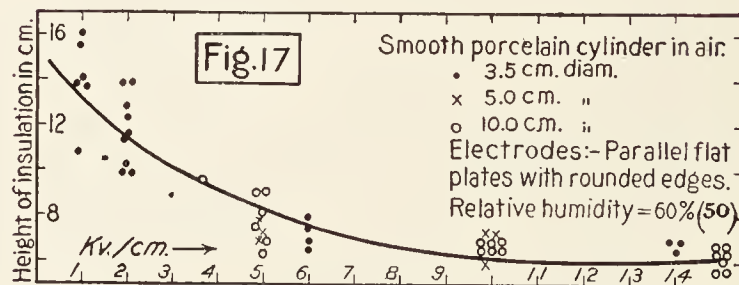
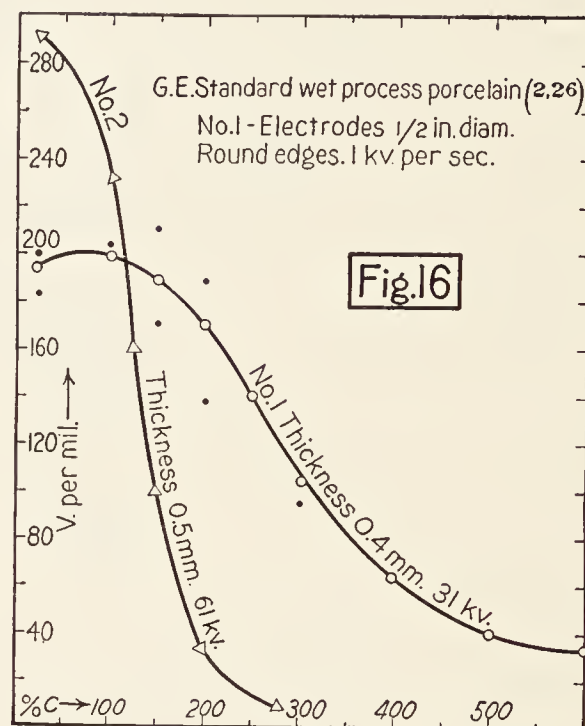
## ELECTROLYSIS OF HOT PORCELAIN

Above  $300^\circ$  porcelain behaves as an electrolytic conductor, the alkali metals migrating toward the cathode. For experimental details, results and conclusions, v. Haber (23).

## VELOCITY OF SOUND

Velocity km/sec	Type	Lit.	Velocity km/sec	Type	Lit.
5.63	Insulator H	(46)	5.05	Hermendorf hard	(46)
5.34	Seger 6833	(46)	4.9-5.2	In general	(56)

Velocity of transmission, or vibration of sound, varies with the modulus of elasticity. Porcelains having the highest velocity are the best. Velocity increases with increasing clay content.





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(For a key to the periodicals see end of volume)

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- (<sup>40</sup>) Riddle and Laird, *38*, 5: 500; 22. (<sup>41</sup>) Rieke, *103*, 22: 143; 14. (<sup>42</sup>) Rieke, *92*, 28: 374; 15. (<sup>43</sup>) Rieke and Gary, *B5*. (<sup>44</sup>) Rosenthal, *100*, 48: 445; 15. (<sup>45</sup>) Rosenthal and Singer, *101*, 41: 705; 20. (<sup>46</sup>) Rosenthal and Singer, *103*, 29: 81, 93; 21. (<sup>47</sup>) Roth, *100*, 55: 533; 23. (<sup>48</sup>) Royal, Champion Porcelain Co., Detroit, O. (<sup>49</sup>) Rziha and Seidener, *B8*.
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## II. LABORATORY PORCELAINS AND WHITEWARES

JAMES A. AUDLEY<sup>1</sup>

## A Classification of Porcelains and Whitewares Based on Their Composition and Properties

## I. Body vitrified Little or no porosity.

## (A) Porcelain. More or less translucent.

## 1. Hard porcelain.

Body and glaze fired up together to a comparatively high temperature, with or without a previous low fire biscuiting. Glaze composition approximating that of the body, but with lime and often zinc oxide added.

## 2. Soft porcelain.

## (a) Seger porcelain.

## (b) Frit porcelain.

## (c) Bone porcelain.

## (d) Belleek.

## (e) Parian (biscuit or figure porcelain).

## (B) Stoneware. Not translucent.

## II. Body not completely vitrified, porous.

## (C) General whiteware (earthenware).

This includes a variety of wares which pass under different trade names (semi-porcelain, white granite, etc.), but almost imperceptibly grade into one another, and into porcelain at one extreme.

Examples illustrating composition are given further on.

Wall tiles and floor tiles may be of porcelain, stoneware, or earthenware. They are made chiefly by the dry press process.

<sup>1</sup> Acknowledgments are due to Dr. J. W. Mellor for the free use of his library, which is rich in scientific and technical literature, and for occasional assistance kindly rendered in tracing important references.

Electrical porcelain possesses properties which give it a distinct value for certain technical purposes, so that it is impracticable to draw any hard and fast lines between it and some other porcelains. For electrical porcelains proper, *v. p.* 67.

## Chemical Composition of Fired Body and Batch Composition of Raw Body

For composition limits assigned to the various types of porcelain and whiteware, *v.* the standard works such as those of Seger, Kerl, Bourry, Granger, etc., and special works such as (82, 99, 119).

The actual compositions of some of the bodies whose properties are listed in the following pages are appended hereto, together with the reference numbers by which they are identified in the subsequent pages.

## BODY COMPOSITION, Wt. %

Ref. No.	6	7	8	9	10	11	12	13	14	15	16	17	18
Kaolin.....	55	60	60	60	55	55	55	55	50	50	50	50	50
Quartz.....	22.5	25	20	15	30	25	20	15	35	30	25	20	15
Feldspar.....	22.5	15	20	25	15	20	25	30	15	20	25	30	35

Ref. No.	19	20	21	22	23	24	25	26	27	28	29	30	31
Kaolin.....	45	45	45	45	40	40	40	55	55	55	55	55	65
Quartz.....	35	30	25	20	35	30	25	40	30	22.5	15	5	25
Feldspar.....	20	25	30	35	25	30	35	5	15	22.5	30	40	10

Ref. No.	32	33	34*	35†	36†	37	38	39
Kaolin.....	65	65	25	30	35	43.4	40.5	52.0‡
Quartz.....	17.5	10	45	12	11	29.5	25.1	
Feldspar.....	17.5	25	30	60	54	25.6	29.2	42.0
CaCO <sub>3</sub> .....						1.5	5.2	6.0

\* Seger porcelain. † Figure porcelain. ‡ Sornzig kaolin.

Ref. No.	40	41	42	43	44	45	46	47	48	49
China clay....	30	30	30	30	30	30	15		30	30
Ball clay.....	25	25	25	25	15	35	40	20	25	25
Flint.....	30	20	10		30	10		15		20
Feldspar.....	15	25	35	45	25	25	45	30	35	10
Red clay.....								35		
Zirconia.....									10	
Steatite.....										15

Ref. No.	50	51	52	53	54	55	56	57	58
Clay.....	60	65	70	65	70	75	70	75	80
Quartz.....	20	15	10	20	15	10	20	15	10
Feldspar.....	20	20	20	15	15	15	10	10	10

Ref. No.	59	60	61	62	63	64	65	66	67	68
Clay.....	60	55	50	45	40	60	55	50	45	40
Flint.....	20	22.5	25	27.5	30	25	30	35	40	45
Feldspar.....	20	22.5	25	27.5	30	15	15	15	15	15

Ref. No.	69	70	71	72	73	74	75	76	77	78
Clay.....	60	55	50	45	40	60	55	50	45	40
Flint.....	20	25	30	35	40	15	20	25	30	35
Feldspar.....	20	20	20	20	20	25	25	25	25	25

Ref. No.	79	80	81	82	83	84	85	86	87	88	89
Clay.....	60	55	50	45	40	35	65	40	45	50	55
Flint.....	10	15	20	25	30	35	10	25	20	15	10
Feldspar.....	30	30	30	30	30	30	25	35	35	35	35

Ref. No.	90	91	92	93	94	95	96	97	98	99	100
Clay....	40	50	40	40	40	40	40	50	50	50	
Flint....	20	10	31.20	22.85	13.50	42.90	38.60	34.25	14	28.70	23.30
Feldspar	40	40	28.80	37.15	46.50	15.20	19.20	23.00	36	19.10	24.00
Whiting						1.80	2.26	2.75		2.28	2.70

BODY COMPOSITION, WT. %.—(Continued)

Ref. No.	101	102	103	104	105	106	107	108	109
Clay, raw.....	50	50	50	50	50	50	50	50	50
Clay, calcined.....	20	20	20	20	20	25	25	25	25
Flint.....	18.5	13.5	9.5	5.0		13.5	10	5	
Feldspar.....	10	15	19	23.5	28.5	10	13.5	18.5	23.5
Whiting.....	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5

Ref. No.	110	111	112	113	114	115
Clay, raw.....	50	50	50	50	50	50
Clay, calcined.....	30	30	30	35		
Flint.....	8.5	5			32.5	34
Feldspar.....	10	13.5	18.5	13.5	16	16
Whiting.....	1.5	1.5	1.5	1.5	1.5	

Ref. No.	116	117	118	119	120	121	122	123	124
Clay.....	71.5	77.0	80.1	85	80	80	75	75	75
Feldspar.....	15	2.5	9.5	13.5	18.5	13.5	23.5	18.5	10
Flint.....	2.4					5		5	13.5
Whiting.....	1.4	1.45	1.43	1.5	1.5	1.5	1.5	1.5	1.5
Alumina.....	9.1	9.05	8.97						

Ref. No.	125	126	127	128	129	130	131	132
Clay.....	70	70	70	80	75	70	50	50
Feldspar.....	23.5	19	15	10	15	10	16	16
Flint.....	5	9.5	13.5	8.5	10	13.5	32.5	34
Whiting.....	1.5	1.5	1.5	1.5	1.5	1.5	1.5	

Ref. No.	136	137	138	139	140	141	142
Kaolin.....	39	39	39	39	39	39	39
Ball clay.....	6	6	6	6	6	6	6
Flint.....	37	37	37	37	37	37	37
Feldspar.....	18	18	18	18	18	18	18
Whiting.....	3	2.5	2	1.5	1	0.5	0
Dolomite.....	0	0.5	1	1.5	2	2.5	3

Ref. No.	143	144	145
Kaolin.....	48	46	46
Quartz.....	18	28	33
Feldspar.....	34	26	21

Ref. No.	158	159	160	161	162	163	164	165
Clay substance.....	50	41	40	62	48	51.5	50	55
Quartz sand.....	22.5	54	52	33	42	43.5	42	40
Feldspar.....	22.5	5	5	5		5	5	5
Chalk.....			3		10		3	

Ref. No.	166	167	168	169	170	171	172	173	174
Clay.....	24*	23*	25†	22‡	24‡	23‡			
Kaolin.....	33	32	50	45	48	46	35	35	25
Quartz.....	38	37	20	22	23	23	60	60§	45
Feldspar.....	5	5	5		5	5	5	5	30
Chalk.....		3		10		3			

\* Lean clay. † Fat clay. ‡ Meissen clay. § Quartz sand calcined twice at cone 15.

BODIES, CHEMICAL COMPOSITION

Ref. No.	1*	2*	3*	4*	5†	6‡
SiO <sub>2</sub> .....	60.75	69.37	74.52	79.32	70.7	67.5
Al <sub>2</sub> O <sub>3</sub> .....						26.6
TiO <sub>2</sub> .....	32	23.61	2.70	18.42	23.4	0.4
Fe <sub>2</sub> O <sub>3</sub> .....						0.8
CaO.....	4.15	1.22	16.10	0.36		0.4
MgO.....	0.08	0.08	0.61		1.0	0.3
K <sub>2</sub> O.....		2.58	3.45	1.82		3.3
Na <sub>2</sub> O.....	3.02	2.42	2.63	0.32	4.8	0.7

BODIES, CHEMICAL COMPOSITION.—(Continued)

Ref. No.	101	102	103	104	105	106	107	108	109
SiO <sub>2</sub> .....	64.59	62.90	61.61	60.10	58.52	62.07	60.90	59.27	57.64
Al <sub>2</sub> O <sub>3</sub> .....	30.86	31.76	32.53	33.36	34.25	33.15	33.80	34.70	35.63
TiO <sub>2</sub> .....	0.15	0.15	0.15	0.15	0.15	0.17	0.17	0.17	0.17
Fe <sub>2</sub> O <sub>3</sub> .....	0.53	0.55	0.57	0.61	0.63	0.56	0.58	0.60	0.64
CaO.....	1.07	1.08	1.09	1.10	1.12	1.09	1.11	1.15	1.14
MgO.....	0.22	0.23	0.23	0.24	0.25	0.23	0.24	0.25	0.25
K <sub>2</sub> O.....	1.58	2.08	2.47	2.92	3.40	1.61	1.97	2.45	2.96
Na <sub>2</sub> O.....	1.05	1.25	1.35	1.52	1.68	1.12	1.23	1.41	1.57

Ref. No.	110	111	112	113	115	133	134	135
SiO <sub>2</sub> .....	59.56	58.36	56.80	55.93	72.51	72.49	71.40	75.64
Al <sub>2</sub> O <sub>3</sub> .....	35.43	36.08	37.00	38.40	22.60	22.03	27.58	22.63
TiO <sub>2</sub> .....	0.18	0.18	0.18	0.19	0.16			
Fe <sub>2</sub> O <sub>3</sub> .....	0.63	0.65	0.62	0.66	0.44	3.66	0.75	0.68
CaO.....	1.10	1.12	1.13	1.13	1.05	Trace	0.35	0.68
MgO.....	0.26	0.27	0.28	0.28	0.18	0.24	0.06	0.06
K <sub>2</sub> O.....	1.67	2.05	2.53	2.07	1.96		2.22	2.61
Na <sub>2</sub> O.....	1.17	1.29	1.46	1.34	1.08			
Ig. loss.....							0.10	0.22

Ref. No.	151	152	153	154	155	156	157
SiO <sub>2</sub> .....	68.4	70.00	69.52	67.65	76.45	71.27	75.02
Al <sub>2</sub> O <sub>3</sub> .....	27.7	26.21	26.56	27.74	18.90	25.24	23.40
Fe <sub>2</sub> O <sub>3</sub> .....	0.82	0.75	0.76	0.73	1.01	0.71	0.15
CaO.....	0.3	0.54	0.51	0.63	0.93	0.72	0.61
K <sub>2</sub> O.....	1.37	1.45	1.34	1.38	0.97	1.74	
Na <sub>2</sub> O.....	1.03	0.88	0.87	0.97	1.35	0.81	0.89

Ref. No.	159	160	161	162	163	164
SiC.....	74.6	72.4	60.5	62.7	68.9	67.0
Al <sub>2</sub> O <sub>3</sub> .....	17.1	16.6	25.2	19.1	20.8	20.2
Fe <sub>2</sub> O <sub>3</sub> .....	0.8	0.7	1.5	0.8	0.9	0.8
CaO.....	0.4	1.9	1.5	6.0	0.9	2.5
MgO.....			0.6	0.5	0.5	0.5
K <sub>2</sub> O.....	1.7	1.7	2.2	0.5	1.2	1.2
Ig. loss.....	5.6	6.7	9.3	10.9	6.8	7.8

\* Sèvres hard porcelain, new body, soft porcelain and stoneware, respectively, according to Coupeau (20, 21). † Limoges porcelain according to Vogt (20, 21). ‡ Berlin porcelain, general chemical composition according to Rieke (103).

DISTRIBUTION OF REFERENCE NUMBERS (COMPOSITIONS) AMONG LITERATURE REFERENCES

Ref. No.	Lit.	Ref. No.	Lit.	Ref. No.	Lit.
1-5	(20, 21)	36	(158, 159)	101-115	(93)
6	(18, 19, 103, 105, 129, 158, 159)	37-39	(33)	116-132	(127)
		40-49	(144)	133	(134)
		50-58	(72)	134, 135	(90)
		59-84	(74, 77, 85)	136-142	(94)
7-25	(106)			143-145	(138)
15	(56, 57)	85-91		151-157	(25, 26)
16	(106, 114)	52, 69		158	(18, 19)
26-33	(112)	73-79	(80, 84)	159-164	(42)
34	(105, 129, 158, 159)	81		165	(58)
		92-100	(76)	166-171	(88, 89)
35	(105, 129)			172, 173	(101, 102)

### Petrographic Character of Laboratory Porcelains and Whiteware

The petrographic character of a ceramic body made from clay, feldspar, and flint varies according to the proportions of the component materials and also with the method of preparation (involving physical conditions) and conditions of firing. In porcelains wide variations occur in the relative amounts of glassy



matrix, undissolved quartz (or cristobalite), undecomposed or undissolved clay, and mullite ( $3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$ ). The mullite was for a long time regarded as sillimanite ( $\text{Al}_2\text{O}_3 \cdot \text{SiO}_2$ ), discrimination being difficult owing to the close resemblance, *v.* p. 68.

A good porcelain of the kind indicated should consist largely of a feldspathic glassy matrix with embedded crystals of quartz and mullite distributed evenly, but no visible particles of clay. The quartz should not exceed 20, or at most 25% and the average size of its particles should not exceed 0.03 to 0.04 mm diameter, all edges and corners being rounded off through partial solution in the matrix. The crystals of mullite should be numerous and well

formed, and should not exceed *ca.* 0.01 mm in length and 0.002 mm in thickness. Porcelains answering to this description can be produced only at a comparatively high firing temperature. With lower temperatures smaller proportions of glassy matrix and mullite crystals are produced, the proportions diminishing gradually until the crystals cease to be formed and the amount of glassy matrix becomes relatively insignificant, and the product is no longer porcelain but simply white earthenware.

For the microscopic characters of thin sections of porcelains and whitewares, *see* (56, 57, 67, 68, 69, 79, 90, 91, 92, 108, 150, 158, 159).

## BULK DENSITY, SPECIFIC GRAVITY, AND POROSITY

Specific gravity	Bulk density	% open pore porosity*	% total porosity	Type	Lit.
2.3 -2.5†	2.15-2.02			Bayeux hard porcelain at red to white heat	(115)
2.60-2.64†				Hard porcelain	(29)
2.46				<i>Idem.</i> , baked at <i>ca.</i> 950°C	(29, 103)
2.46	2.32		4.4	Berlin technical porcelain	(103)
2.30-2.40				Berlin hard porcelain	(119, 121)
	1.45-1.55			Hermsdorf porcelain	(32)
	2.27-2.38		4.1 - 7.9	Hermsdorf porcelain, baked	(32)
2.42-2.49				8 commercial porcelains	(108, 118, 119)
2.49				Meissen porcelain	(123)
2.24				Sèvres porcelain	(123)
2.38				Chinese porcelain	(123)
2.44				Laboratory porcelain (Rosenthal)	(123)
2.26				Seger porcelain (Rosenthal)	(123)
2.28				Rosenthal porcelain	(123)
2.36				Japanese porcelain	(134)
2.47-2.53	2.27-2.41		3 -10	19 trial porcelains, fired at cone 12	(80)
		0.010- 0.034	0.00- 1.76	6 American commercial porcelains, cone 12	(157)
		0.05 - 9.7		10 trial porcelains, cone 10	(144)
	2.35-2.39	0.02 - 0.86		26 trial porcelains, cone 10	(77)
	1.96-2.12	6.4 -11.6		3 American hotel chinaware	(128)
	2.03-2.40	0.0 - 9.8		4 American hotel semi-porcelains	(128)
	1.98-2.10	7.4 -10.2		14 American hotel wares	(125)
	2.13-2.33	2.7 - 6.0		8 American household wares (semi-vitreous)	(125)
	2.18-2.35	0.0		4 English hotel wares	(125)
2.53	2.32	0.13	8.5	3 French and German hotel wares	(125)
2.45	2.23	1.80	8.9	Fine stoneware 528	(119)
2.45	2.28	0.19	7.7	Fine stoneware DTS sill. 54	(119)
1.33-1.65		17.1 -21.6		Fine stoneware, DTS sill. 55	(119)
2.48-2.54	2.15-2.20		11.8 -15.2	6 earthenware bodies, cone 4a	(42)
				4 stonewares	(121)

\* For direct determination of pore volume, *v.* (142). Different absorption methods (140).

† For effects of firing temperatures and fineness of grinding, *v.* (42, 62, 63, 80, 84, 94, 105).

## SPECIFIC GRAVITY AND BULK DENSITY (13)

Specific gravity	Bulk density	Type
2.628	2.363	Palissy faience
2.884	2.354	Nevers faience
2.789	2.363	Rouen faience
2.564	2.433	Creil fine faience
2.482*		Creil fine faience
2.482	2.226	English fine faience
2.567	2.455	Flemish stoneware
2.610	2.556	Japanese stoneware
2.505	2.436	English stoneware
2.569	2.508	Hard porcelain from Saxony
2.531	2.314	Bayeux hard porcelain

## SPECIFIC GRAVITY AND BULK DENSITY (13).—(Continued)

Specific gravity	Bulk density	Type
2.556	2.133†	Sèvres hard porcelain (1798)
2.527	2.259†	Sèvres hard porcelain (1788)
2.470	2.334	Limoges hard porcelain
2.500	2.290	Chinese hard porcelain
2.525	2.384	English soft porcelain
2.525	1.873	Sèvres soft porcelain
2.477	2.143	Tournay soft porcelain

\* After firing with Sèvres hard porcelain. Specific gravities of other bodies are given in the same table.

† Pores very visible.

## COEFFICIENT OF CUBICAL COMPRESSIBILITY

*See* p. 68. *Cf.* (29, 32, 123).

## MODULUS OF RUPTURE (DEF. 5)

kg/cm <sup>2</sup>	Type	Lit.
774-943	Berlin technical porcelain	(107, 108, 119)
588-777	7 commercial porcelains, other than Berlin	(107, 108, 119)
420-560	Hermisdorf porcelain	(32, 113, 123)
>690	Hermisdorf porcelain	(119)
550-670	Hermisdorf porcelain	(35)
930	A special Hermisdorf porcelain	(35)
590	Rosenthal insulator G porcelain	(113, 119, 123)
540	Rosenthal insulator II porcelain	(113, 119, 123)
640	Rosenthal table porcelain	(113, 119, 123)
410	Rosenthal laboratory porcelain	(113, 119, 123)
520	Trial porcelain 6292 (copied from American insulator porcelain)	(113, 119, 123)
106-185	6 trial earthenwares, cone 8-9, Ref. No. 159-164*	(42)
233	Faience body 135	(119)
416	Fine stoneware, DTS sill. 54	(119)
580	Fine stoneware, DTS sill. 55	(119)
980	Special trial stoneware 6412	(113, 119, 123)

Extruded cylindrical rods 16 mm diameter are fired hanging vertically, and sawn to 120 mm lengths. Loaded centrally, between steel knife edge supports, 1 kg/sec.

\* Values for firings at cones 01a and 4a are also given in this paper.

## TENSILE STRENGTH (DEF. 4)

kg/cm <sup>2</sup>	Type	Cross section, * cm <sup>2</sup>	Lit.
1000-2000	Hard porcelain		(29)
280-363	Berlin technical porcelain	2.5-2.9	(107, 108, 121)
161-265	7 commercial hard porcelains (other than Berlin)	2.8-3.9	(107, 108, 119)
>360	Hermisdorf porcelain		(119)
360-420	Hermisdorf porcelain	3.14	(35)
ca. 261	Rosenthal insulator porcelain H		(113, 123)
500	Chinese porcelain		(119)
106-887	American porcelain		(119)
258-396	19 trial porcelains, cone 15, Ref. No. 7-25		(106)
180-240	Soft porcelain, cone 8-9	3.50-3.63	(33)
184-283	Soft porcelain, cone 8-9	2.76-3.40	(33)
84-191†	10 trial porcelains fired to vitrification, cone 7-10, Ref. No. 40-49	ca. 3.2	(144)
108-185	6 trial earthenwares fired at cone 8, Ref. No. 166-171†		(88, 89)
44-80	6 trial earthenwares fired at cone 8-9, Ref. No. 159-164†		(42)
118	Special hard earthenware 237		(119)
67	Faience body 135		(119)
178	Fine stoneware DTS sill. 54		(119)
163	Fine stoneware DTS sill. 55		(119)

\* The area of the cross section of the test piece is important. On comparing the tensile and crushing strengths of German and American porcelains, it may be noted that, in general, the former have greater crushing strength and the latter greater tensile strength.

† The respective values in order of the composition Ref. No. 40-49 are 125.8, 126.5, 126.5, 109.7, 123, 83.7, 92.1, 126.5, 191.2, and 141.3.

‡ Values for firings at cones 01a and 4a are also given in this paper. For other measurements of tensile strengths of trial bodies, v. (145). For influence of glaze, v. p. 68.

CRUSHING STRENGTH  
Unit = 1000 kg./cm<sup>2</sup>

Strength	Type	Remarks	Lit.
4-5	Hard porcelain		(14, 15, 113, 119)
4.2	Hard porcelain		(112, 123)
ca. 4.2	Berlin technical porcelain	2.5 cm cubes, determined by Rosenthal	(103)
>5.6	Hermisdorf porcelain		(32, 119, 123)
4.8	Hermisdorf porcelain		(32, 113)
4.5-5.5	Hermisdorf porcelain	16 mm diam., 16 mm long	(35)
2.8-4.6	American porcelain		(119)
7.43	Porcelain 152		(119)
2.7-4.2	8 trial porcelains, cone 16, Ref. No. 26-33*	2 cm diam. cylinders (with 3.14 cm <sup>2</sup> cross section)	(112)
2.7-4.0	7 trial porcelains, cone 11		(94)
2.8-4.5	6 American commercial porcelains, cone 11	Cylinders ca. 3.1 cm when just formed	(157)
0.04-0.08	6 trial earthenwares, cone 8†, Ref. No. 166-171		(88, 89)
5.8	Fine stoneware, DTS sill. 55		(119)

The higher values (5 and over) are probably due to the use of cylindrical instead of square test pieces. In 1920 the German Committee specified test pieces 16 mm diameter and 16 mm long.

\* Highest value given by body with 55 % Zettlitz kaolin and 22.5 % each of quartz sand and feldspar. Only a little inferior were the values for bodies having 15 % feldspar and 30 % quartz, and 30 % feldspar and 15 % quartz, respectively.

† Value for firings at cones 01a and 4a are also given in this paper.

## CRUSHING STRENGTH BETWEEN SPHERES\*

kg	Type	Lit.
118-152	Berlin technical porcelain	(107, 108, 119)
76-137	7 commercial hard porcelains (other than Berlin)	(107, 108, 119)
50-94	19 trial porcelains fired at cone 15, Ref. No. 7 to 25	(106)
96 (90-99)	Trial soft porcelain	(33)
526	Faience body 135	(119)
792	Fine stoneware, DTS sill. 54	(119)
982	Fine stoneware, DTS sill. 55	(119)

\* Gary press, v. p. 69 (34, 107, 108). The last three values are those of the breaking load—as are some of the others given in (119) and elsewhere—and are about 10 times as large as they should be. Unfortunately, the details are not available.

## MODULUS OF ELASTICITY (DEF. 10)

The unit is 1000 kg/mm<sup>2</sup>

Modulus	Type	Remarks	Lit.
5.4-7.1	Hermisdorf porcelain		(29, 32, 123)
7-8	Hermisdorf porcelain		(119)
8.7-7.4	Hermisdorf porcelain		(35)
8.2-8.4	Berlin technical porcelain	Bending. Av. of 72 tests	(107, 121, 123, 131)
7.1	Sèvres hard porcelain	Fired at 1370°	(62, 63)
6.7	Sèvres new porcelain	Fired at 1270°	(62, 63)
5.0	Sèvres soft porcelain	Fired at 1100°	(62, 63)
2.5	Sèvres stoneware	Fired at 1270°	(62, 63)
3.7	Fine faience	Fired at 1270°	(62, 63)



## MODULUS OF ELASTICITY (DEF. 10).—(Continued)

Modulus	Type	Remarks	Lit.
8.4	Rosenthal insulator porcelain G and H	Bending	(123)
7.8	Rosenthal insulator porcelain G and H	Bending	(119)
9.1	Rosenthal table porcelain	Bending	(123)
8.1	Rosenthal table porcelain	Bending	(119)
8.6	Rosenthal trial porcelain 6292	Bending	(123)
14.9	Rosenthal trial stoneware 6412	Bending	(123)
8.9	Rosenthal laboratory porcelain		(119)
6.8	Rosenthal Seger porcelain 6833		(119)
6.5	Chinese porcelain		(119)
2.4	Faience body 135		(119)
5.1	Fine stoneware DTS sill. 54		(119)
6.5	Fine stoneware DTS sill. 55		(119)
151	Trial stoneware 6412		(119)

The value of the modulus changes (usually inversely) with the load. It depends less upon chemical composition than upon conditions of manufacture. It is substantially the same for tension and compression.

## MODULUS OF ELASTICITY IN SHEAR (DEF. 11)

kg/cm <sup>2</sup>	Type	Lit.
430	Trial Seger porcelain Body 6833 (Rosenthal)*	(113)
481	Rosenthal insulator Body G	(113, 119)
500	Rosenthal insulator Body H	(113, 119)
500	Rosenthal laboratory porcelain	(113, 119)
480-600	Hermesdorf porcelain	(119)
226	Fine stoneware 238	(119)
323	Fine stoneware DTS sill. 54	(119)
169	Faience Body 135	(119)
232	Special hard earthenware 237	(119)
246	Special body 240	(119)

\* Square cross section.

FIXED IMPACT AND BENDING SHOCK (DEF. 16)  
Pendulum-hammer method (34, 108, 119)

em-kg/cm <sup>2</sup>	Type	Lit.
2.0	Berlin technical porcelain	(107, 108, 119, 121)
1.75-1.95	7 commercial porcelains (other than Berlin)	(107, 108, 119)
1.9	Hermesdorf porcelain	(119)
1.9-2.3	Hermesdorf porcelain	(35)
0.90	Rosenthal insulator porcelain G	(113, 119, 123)
0.95	Rosenthal insulator porcelain H	(113, 119, 123)
1.36	Rosenthal table porcelain	(113, 119, 123)
1.23	Rosenthal laboratory porcelain	(113, 119, 123)
0.08	Rosenthal trial hard porcelain 6292 (copied from American insulator porcelain body)	(113, 119, 123)
1.0	Rosenthal Seger porcelain 6833	(113, 119, 123)
2.4	Rosenthal trial porcelain 6412	(113, 119, 123)
1.61*	Rosenthal trial porcelain 6048	(113, 123)
1.76-1.95	19 trial porcelains fired at cone 15, Ref. Nos. 7-25	(106)

## FIXED IMPACT AND BENDING SHOCK (DEF. 16).—(Continued)

em-kg/cm <sup>2</sup>	Type	Lit.
1.23-1.8	8 trial porcelains, Ref. No. 15 considered the best	(138)
1.68-1.92	Soft porcelain, conc 8-9	(33)
1.6	Faience body 135	(119)
2.0	Hard earthenware 236	(119)
1.5	Hard earthenware 237	(119)
1.7	Earthenware 240	(119)
1.7	Fine stoneware 238	(119)
1.8	Fine stoneware DTS sill. 54	(119)
1.7	Fine stoneware DTS sill. 55	(119)
1.3-1.9	Stonewares Z58, Z59, Z60, Z61	(121)

\* In (123) this value is given as 1.38, but the 1.61 occurs twice in (113).

See also (125) for a different impact test.

## SUCCESSIVE INCREASING IMPACT SHOCKS

Marten's method

112 cm × kg/cm<sup>3</sup> for a table porcelain (113); see also p. 70

## RESISTANCE TO ABRASION\*

Gary sand blast test, 2 min at 3 atm

Type	Loss in cm <sup>3</sup>	Lit.
Stoneware 6412 (Rosenthal).....	1.7	(113, 123)
Faience body 135.....	7.2	(119)
Special hard earthenware 236.....	5.8	(119)
Special hard earthenware 237.....	5.9	(119)
Fine stoneware 238.....	2.4	(119)

\* In (123, p. 57) Singer quotes from (32) results for hardness obtained by Linck with the use of the sclerometer, and the corresponding values according to the hardness scale of Mohs, as follows:

	Sclerometer number	Number in Mohs scale
Easy baked porcelain.....	10-12	2
Hard baked porcelain.....	22-25	2.5
Porcelain fired to maturity, unglazed.....	550-650	7
Surface layer of glaze.....	950-1000	8
Glaze below the surface.....	350-400	6.3

## TOUGHNESS AND HARDNESS BY THE RATTLER TEST

% loss of weight by rattler test			Type	Lit.	% loss of weight by rattler test			Type	Lit.
15 min	60 min	Ref. No.			15 min	60 min	Ref. No.		
1.93	4.62	92	(76)		4.42	8.21	70	(77)	
0.68	1.95	93	(76)		2.33	5.09	71	(77)	
1.57	4.33	94	(76)		2.30	4.39	72	(77)	
0.30	0.88	95	(76)		1.96	4.12	73	(77)	
0.58	1.97	96	(76)		5.66	10.23	74	(77)	
1.17	3.31	97	(76)		5.19	8.22	75	(77)	
1.73	3.46	98	(76)		2.51	5.45	76	(77)	
1.95	3.70	99	(76)		2.82	5.65	77	(77)	
1.96	4.95	100	(76)		5.02	8.51	79	(77)	
5.36	13.94	59	(77)		4.33	8.02	80	(77)	
6.10	15.36	60	(77)		3.38	6.34	81	(77)	
5.18	14.73	61	(77)		2.71	4.80	82	(77)	
4.77	9.32	64	(77)		2.19	4.78	83	(77)	
1.06	5.54	65	(77)		1.98	4.17	84	(77)	
4.03	7.43	69	(77)						

% loss of weight by rattler test				Type (94)	% loss of weight by rattler test				Type (94)
15 min	30 min	180 min	Ref. No.		15 min	30 min	180 min	Ref. No.	
4.67	6.38	11.25	136		3.66	5.20	10.70	140	
4.09	5.60	11.40	137		3.60	5.15	9.80	141	
4.47	5.98	12.80	138		3.05	4.12	10.30	142	
2.95	4.60	9.42	139						

The 15 min test serves to indicate the toughness or resistance to chipping.

The 180 min test indicates hardness after edges and corners have been removed.

These rattler tests were made in a ball mill 9¾ in. diameter and 13 in. long inside, making 40 revolutions per minute. The charge consisted of 61 nearly equal pebbles, weighing 22¾ lb. For each test 13 specimens of porcelain were used, which were weighed at the proper time intervals. For a standard test it is suggested that 10 kg of pebbles might be used along with 12 specimens. The above results of tests are comparable, as the same conditions were maintained throughout.

Further data relating to the rattler test with trial bodies will be found in (53, 65, 128, 145).

#### SOFTENING POINT AND CONE MELTING POINT

°C	Type and remarks	Lit.
1500	Normal	(122)
1700	Special	(122)
1710	Rosenthal porcelain melts	(119, 120, 123)
1390	Japanese table porcelain, Ref. No. 133	(134)
1690	Porcelain, Ref. No. 134 melts	(90)
1670	Porcelain, Ref. No. 135 melts	(90)
	Berlin porcelain	
900-1000	Appreciable softening begins	(103, 123)
ca. 1680	Melting takes place	(103, 119, 123)
ca. 950	Berlin glaze softens	(103, 123)
Cone		
25	Berlin porcelain begins to deform	(72)
25	Ref. No. 58 begins to deform	(72)

Softening point varies with size and shape of test piece and also with time of heating, etc.

In spite of the softening of Berlin porcelain, perceptible far below 1000°C according to Rieke (103, 123), porcelain tubes, crucibles, etc., if suitably protected and not too severely loaded, can be safely used at temperatures up to 1400° or even higher. For Rosenthal porcelain it is claimed that when very strongly heated it can be worked like glass to make laboratory apparatus, see (120).

Rosenthal (112) heated one side of thick rods of different hard porcelains in an electric arc-light. He found that bodies rich in feldspar immediately split off in numerous small pieces, bodies rich in quartz and clay substance cracked off more slowly and in larger pieces, whilst specially resistant bodies merely melted at the heated places.

#### COEFFICIENT OF THERMAL EXPANSION

$\frac{10^6 \Delta l}{l \Delta t}$	Type	Range °C	Lit.
3.43	Berlin technical porcelain, unglazed.	23-200	(29, 101, 102, 103, 119)
3.53		23-400	(101, 102, 103, 119)
3.55		23-600	(101, 102, 103)
3.56		23-700	(29, 101, 102, 103)
1.77		-191 to 16	(49, 101, 102, 103, 123)
3.36	Berlin porcelain.....	16-250	(49, 101, 102, 103, 123)
3.64		16-500	(49, 101, 102, 103, 123)
3.77		16-750	(49)
4.34		16-1000	(49, 101, 102, 103, 119, 123)
3.16		0-250	(50)
3.50		0-500	(50)
3.60		0-750	(50)
4.09		0-1000	(50)
ca. 4.4		>1000	(52)
3.76		0-625	(51)

#### COEFFICIENT OF THERMAL EXPANSION.—(Continued)

$\frac{10^6 \Delta l}{l \Delta t}$	Type	Range °C	Lit.
ca. 1.79	Berlin porcelain.....	-191 to 16	(117, 118)
2.94		14-56	(117, 118)
3.08		14-100	(117, 118)
2.99		0-100	(14, 15, 16, 17)
3.12			(100)
3.8			(119, 121)
3.03-4.31		Various up to 1000*	(119)
4.25			(119)
3.80		20-100	(123)
3.52		20-100	(123)
3.60-4.79	Rosenthal elec. porcelain.....	0-100	(119)
2.69	Meissen porcelain.....	0-99	(101, 102, 123, 153)
5.4	Hermisdorf porcelain.....	0-1106	(115)*
5.3		0-1298	(20, 21, 115)
5.3		0-1457	(20, 21, 115)
6.8		0-1524	(20, 21, 115)
2.82-3.81		0-83	(14, 15, 20, 21)
2.522		0	(101, 102, 123, 135, 136)
2.819		20	(135, 136)
3.166		40	(135, 136)
3.265		50	(101, 102, 123, 135, 136)
3.414		60	(135, 136)
3.711	Bayeux porcelain.....	80	(135, 136)
4.008		100	(101, 102, 123, 135, 136)
4.305		120	(101, 102, 123, 135, 136)
3.53-4.07		100-600	(1, 2, 3, 119)
7.76			
5.71			
5.21			
3.97			
3.74			
3.72-3.60			
5.23	Ref. No. 16, fired at:		
5.01	1000°C .....		(110)
2.99	1100°C .....		(110)
	1250°C .....		(110)
	Cone 15 .....		(110)
	Cone 16 .....		(110)
	Fired more than once		(110)
	Sèvres new porcelain fired at:		
	1270° .....		(20, 21, 25, 26)
	1370° .....		(20, 21, 25, 26)
	1500° .....		(20, 21, 25, 26)
	Sèvres hard porcelain:		
5.1	Fired at 1000° .....	0-200	(20, 21)
6.0		0-400	(20, 21)
6.1		0-600	(20, 21)
5.5		0-800	(20, 21)
3.9		0-200	(20, 21)
4.3		0-400	(20, 21)
4.5		0-600	(20, 21)
4.7		0-800	(20, 21)
13.5		0-200	(20, 21)
14.3		0-400	(20, 21)
5.5	Soft, fired at 1100° .....	0-200	(20, 21)
6.5		0-400	(20, 21)
8.5		0-600	(20, 21)
6.4		0-200	(20, 21)
7.0		0-400	(20, 21)
7.5		0-600	(20, 21)
6.9		0-800	(20, 21)
4.5		0-200	(20, 21)
4.7		0-400	(20, 21)
4.8		0-600	(20, 21)
4.9		0-800	(20, 21)
	Sèvres stoneware:		
4.5	Fired at 1000° .....	0-200	(20, 21)
5.0		0-400	(20, 21)
6.6		0-600	(20, 21)
4.8		0-800	(20, 21)
6.0		0-200	(20, 21)
7.1		0-400	(20, 21)
8.6		0-600	(20, 21)
6.8		0-800	(20, 21)
9.0		0-200	(20, 21)
8.3		0-400	(20, 21)
7.7		0-600	(20, 21)

\* Deville and Troost made more than 200 experiments in air



COEFFICIENT OF THERMAL EXPANSION.—(Continued)

$\frac{10^6 \Delta l}{l \Delta t}$	Type	Range °C	Lit.
7.2	Fired at 1370° .....	0-800	(20, 21)
3.8	Limoges poreelain fired at 1370°	0-200	(20, 21)
4.2		0-400	(20, 21)
4.5		0-600	(20, 21)
4.5		0-800	(20, 21)
5.0		0-200	(20, 21)
6.0	Fine faience (Choisy) fired at 1200°	0-400	(20, 21)
7.8		0-600	(20, 21)
6.3		0-800	(20, 21)
8.1		0-300	(22)
7.2		0-500	(22)
6.8	Body of composition, Al <sub>2</sub> O <sub>3</sub> -2SiO <sub>2</sub> ,† fired at 1250°.	0-700	(22)
6.4		0-900	(22)
7.0		0-300	(22)
8.2		0-500	(22)
9.8		0-700	(22)
9.3	Body of composition, Al <sub>2</sub> O <sub>3</sub> -10SiO <sub>2</sub> ,† fired at 1250°.	0-900	(22)
2.9			(127)
3.4			(127)
3.1			(127)
3.2			(127)
2.9	Ref. No. 116.....	Room temperature to 200°	(127)
3.3			(127)
3.5			(127)
3.2			(127)
4.1			(127)
3.7	Ref. No. 125.....		(127)

COEFFICIENT OF THERMAL EXPANSION.—(Continued)

$\frac{10^6 \Delta l}{l \Delta t}$	Type	Range °C	Lit.
3.3	Ref. No. 126.....	Room temperature to 200°	(127)
3.4	Ref. No. 127.....		(127)
4.7	Ref. No. 128.....		(127)
3.7	Ref. No. 129.....		(127)
6.1	Ref. No. 130.....		(127)
6.2	Ref. No. 131.....		(127)
4.7	Ref. No. 132.....		(127)
5.4	Special hard earthenware 236..		(119)
7.1	Special hard earthenware 237..		(119)
5.7	Fine stoneware 238.....		(119)
4.9	Fine stoneware DTS sill. 55 ...		(119, 121)
4.3-4.9	4 stonewares (58-61)		(119)
	Earthenwares fired at cone 9		
ca. 10.3	Ref. No. 172, 173.....	22-150	(101, 102)
12.2	Ref. No. 172.....	220-340	(101, 102)
10.8	Ref. No. 173.....	220-340	(101, 102)

For other values for Berlin porcelain, *v.* (119, p. 428). For expansion coefficients of bodies with calcined clay replaced by sillimanite (mullite) or other special component, *v.* p. 70, and also (93, 127).

† Chantepie records results obtained with these two bodies fired at 1370°, and also at 1000° in the case of the former; also with bodies obtained by admixture of considerable percentages of iron oxide, feldspar, or chalk respectively with the former, and of lime or magnesia respectively with the latter. Coefficients for the range 200°-400° are also given in (127). Other thermal expansion coefficients, mainly of trial bodies, will be found in (84, 85, 146, 149). For coefficients of thermal expansion of glazes, *v.* (20, 21, 25, 26, 109).

HEAT CAPACITY (SPECIFIC HEAT)

g-cal/g°C	Range	Type	Cone	Lit.	g-cal/g°C	Range	Type	Cone	Lit.
0.258	15-912	Porcelain		(40)	0.212	20-200	Marquardt body	15	(130)
0.256	15-958	Porcelain		(40)	0.229	20-400	Marquardt body	15	(130)
0.254	15-1075	Porcelain		(40)	0.190		Porcelain, Japanese table		(134)"
0.202	20-210	Porcelain, Berlin technical	15	(103, 130)	0.17		Porcelain, hard		(32)
0.221	20-400	Porcelain, Berlin technical	15	(103, 130)	0.25		Porcelain, Rosenthal		(123, 130)†
0.212	20-200	Marquardt body	09	(130)	0.2		Porcelain, Hermsdorf		(119)
0.229	20-400	Marquardt body	09	(130)	0.185-0.187	17-100	Stonewares		(121)

\* A "brown poreelain" (Japanese) used for making bottles with specific heat reported as 0.171, is evidently a stoneware.

† According to Dolazalek, the heat capacity per cm<sup>3</sup> is 0.575, the specific gravity being 2.3.

AVERAGE SPECIFIC HEAT IN MEAN CALORIES BETWEEN 20°C AND

°C	100	200	300	400	500	600	700	800	900	1000	1100	Lit.
Berlin porcelain, green*.....	0.185	0.187	0.197	0.213	0.228							(18, 19)
Berlin porcelain, fired.....	0.189	0.195	0.203	0.212	0.222	0.232	0.245	0.264	0.287	0.304	0.337	(18, 19)
Berlin porcelain, glaze, green ..	0.170	0.174	0.183	0.193	0.208							(18, 19)
Berlin porcelain, glaze, fired ...	0.179	0.181	0.189	0.197	0.199	0.202	0.204	0.211	0.218	0.230	0.245	(18, 19)
Earthenware, green†.....	0.181	0.183	0.192	0.201	0.215							(18, 19)
Earthenware, fired.....	0.186	0.192	0.203	0.212	0.223	0.234	0.275	0.286	0.296	0.307	0.324	(18, 19)

\* For composition, see Ref. No. 6, fired at cone 16 (1460°C).

† For composition, see Ref. No. 158, fired at cone 9.

THERMAL CONDUCTIVITY

Joule cm <sup>-2</sup> sec <sup>-1</sup> (°C, cm <sup>-1</sup> ) <sup>-1</sup>	cal cm <sup>-2</sup> sec <sup>-1</sup> (°C, cm <sup>-1</sup> ) <sup>-1</sup>	BTU <sub>60</sub> ft. <sup>-2</sup> sec <sup>-1</sup> (°F, in. <sup>-1</sup> ) <sup>-1</sup>	Type and remarks	Lit.
0.0104	0.00248 (95°)	0.00200	Porcelain	(64, 119)
0.0185	0.00442	0.00356	Japanese table porcelain	(119, 134)
0.0080	0.0019 (15°-20°)	0.00153	Rosenthal porcelain	(123)
ca. 0.00837	ca. 0.002	ca. 0.00161	Hermsdorf porcelain	(32)
0.00837-0.0167	0.002 -0.004	0.00161-0.00322	Porcelain	(29, 103)
0.0163 -0.0197	0.0039-0.0047 (165°-1055°)	0.00314-0.00379	Sèvres porcelain	(155, 156)
0.0121 -0.0222	0.0029-0.0053 (70°-1000°)	0.00234-0.00427	Stoneware	(155, 156)
0.0113	0.0027	0.00218	Fine stoneware (DTS sill.)	(121)
0.0121	0.0029	0.00234	Stoneware 58	(121)
0.0105	0.0025	0.00202	Stoneware 59, 60, 61	(121)

## RESISTANCE TO THERMAL SHOCK

No standard methods of testing have been adopted, and the recorded data therefore are not comparable; *see* (10, 11, 72, 74, 103, 120, 137, 143, 147, 148, 154).

## SPECIFIC RESISTIVITY (144)

Unit:  $10^{12}$  ohm-cm

Temp., °C	Ref. No.									
	40	41	42	43	44	45	46	47	48	49
20	165	129	109	66	85	109	53	109	109	355
30	80	62	52	31	40	52	25	52	52	173
40	39	30	25	15	20	25	13	25	25	86
50	19	15	13	8	10	13	6	13	11	42
60	9.5	6.3	4.8	3.8	4.2	5.4	2.1	6.3	4.2	21
70	4.8	2.7	1.9	1.7	1.9	2.4	0.9	3.2	1.8	10
80	2.0	1.2	0.8	0.8	0.8	1.0	0.4	1.3	0.8	3.8
90	1.0	0.5	0.3	0.3	0.3	0.5	0.2	0.6	0.3	1.9
100	0.44	0.21	0.17	0.15	0.14	0.18	0.07	0.25	0.13	0.84
120	0.11	0.05	0.04	0.04	0.03	0.04	0.02	0.06	0.03	0.18
140	0.029	0.013	0.011	0.01	0.008	0.011	0.005	0.017	0.008	0.044
160	0.0083	0.0039	0.0032	0.0031	0.0033	0.0036	0.0014	0.0056	0.0024	0.0136
180	0.0028	0.0014	0.0011	0.0011	0.001	0.0012	0.0005	0.002	0.0008	0.0043
200	0.0010	0.0006	0.0004	0.0004	0.0004	0.0005	0.0002	0.0008	0.0003	0.0016

Unit:  $10^9$  ohm-cm

220	0.43	0.21	0.18	0.18	0.18	0.21	0.09	0.31	0.13	0.66
240	0.20	0.10	0.08	0.08	0.07	0.07	0.04	0.14	0.06	0.29
260	0.08	0.051	0.037	0.035	0.035	0.041	0.021	0.073	0.033	0.14
280	0.046	0.029	0.021	0.018	0.021	0.023	0.012	0.041	0.02	0.078
300	0.026	0.016	0.013	0.010	0.012	0.015	0.007	0.033	0.013	0.050

## VOLUME RESISTIVITY

Specific resist. =  $A \times 10^{12}$  ohm-cm

Temp., °C	(A)	Type	Lit.
50	2150	Porcelain	(31)
100	16.1	Porcelain	(31)
150	0.416	Porcelain	(31)
200	0.134	Porcelain	(31)
210	0.00651	Porcelain	(31)
ca. 1000	0.033	Porcelain	(75)
727	0.017	Berlin porcelain	(78, 103)
20	129	Coburg porcelain	(27, 28)*
51	281	Coburg porcelain	(27, 28)
97.5	40	Coburg porcelain	(27, 28)
160.5	1.72	Coburg porcelain	(27, 28)
189	0.385	Coburg porcelain	(27, 28)
400	20	Berlin porcelain, glazed	(36)
600	3.125		(36)
800	1.818		(36)
1000	1.000		(36)
1100	0.769	Meissen porcelain, glazed	(36)
400	20		(36)
600	5.556		(36)
800	2.500		(36)
1000	1.064	Chemical porcelain, unglazed	(36)
1100	0.787		(36)
22	300		(24)
30	220		(24)
2.1	141	Hermsdorf porcelain	(43, 44)
20.5	35.5	Hermsdorf porcelain	(43, 44)
50.4	2.64	Hermsdorf porcelain	(43, 44)
59.1	1.08	Hermsdorf porcelain	(43, 44)
81.9	0.15	Hermsdorf porcelain	(43, 44)

For results of resistivity tests on a typical porcelain body (fired up to 1400°C) at temperatures ranging from 860°–1315°, *v.* (55).

\* Dietrich found no essential difference between glazed and unglazed porcelain.

## TEMPERATURE COEFFICIENTS OF ELECTRICAL RESISTANCE

Berlin porcelain (124)

Temp., °C	$\frac{1}{R_t} \frac{dR}{dt}$	Temp., °C	$\frac{1}{R_t} \frac{dR}{dt}$	Temp., °C	$\frac{1}{R_t} \frac{dR}{dt}$
575	-16.00	725	-2.00	875	-0.35
600	-9.80	750	-1.60	900	-0.30
625	-6.20	775	-1.00	925	-0.25
650	-4.60	800	-0.70	950	-0.20
675	-3.70	825	-0.50	975	-0.16
700	-2.80	850	-0.40	1000	-0.12

## EFFECT OF MOISTURE ON ELECTRICAL RESISTANCE OF POWDERED PORCELAIN (47)

Glazed porcelain		Unglazed porcelain	
Moisture, %	Resistance of a cube of 1 cm edge, kilo-ohm	Moisture, %	Resistance of a cube of 1 cm edge, kilo-ohm
0.43	121 700	1.14	4 521
1.58	12 160	1.54	3 292
1.90	5 953	6.12	1 241
3.34	2 382	9.39	673.8
5.48	563.2	14.1	278.3
8.08	320.7	19.2	40.30
10.9	150.0	23.8	13.78
15.3	39.40	27.3	3.822
19.0	19.32		

## SURFACE RESISTIVITY

This varies enormously with humidity of the atmosphere and with the nature of the surface of the film, *see* (29, 119).

## DIELECTRIC CONSTANT

Dielectric constant	Type	Remarks	Lit.
5.73	Berlin hard porcelain	Ref. No. 6 for composition, sp. gr., 2.38	(129, 103, 119)
6.61	Berlin Seger porcelain	Ref. No. 34, fired at cone 9, sp. gr., 2.40	(103, 129)
6.84	Berlin figure porcelain	Ref. No. 35, sp. gr., 2.41	(103, 129)
4.5–5.3	Hermsdorf porcelain		(29, 32)
5–6	Hermsdorf porcelain		(119)
5.8	Hard porcelain	Ref. No. 16, same value whether potash feldspar or soda feldspar used	(37, 114)
4.38	Baked porcelain*	"Doit être un peu fort"	(23)
8.95	Hermsdorf porcelain at 20°C		(43, 44)
5.17	Fine stoneware, DTS sill. 55		(119)

\* The value is low probably because the test piece was "une plaque de porcelaine dégourdie" or product of the low biscuit firing, and therefore would be very porous.



## DIELECTRIC STRENGTH

1. Shape of the electrodes not specified (except in (112)). Voltage increased 0.5 kv per sec, starting at 20 kv under oil (138)

Volts per mm	Type	Remarks	Lit.
13 200	Ref. No. 26	Test pieces, 10 cm in diam. and about 2.5 mm thick, with rounded edges, under oil. Fired at cone 16	(112)
13 800	Ref. No. 27		
14 000	Ref. No. 28		
13 200	Ref. No. 29		
12 400	Ref. No. 30		
12 800	Ref. No. 31		
13 200	Ref. No. 32		
12 400	Ref. No. 33		

2. Electrodes cup-shaped. Voltage increased 250 volts per sec, starting at 50 % of the estimated puncture voltage (144)

11 150?	Ref. No. 40	Test cups 65 and 69 mm diam. at bottom and top respectively and 65 mm in height. Minimum thickness 3 mm (middle of bottom). Firing temp. resp. cones 10+, 10, 9, 8, 9+, 9, 8, 7, 9, 7. The figures in each case represent the peak value of the puncture pressure, which was found to be 1.46 $\times$ RMS value of puncture pressure	
13 300	Ref. No. 41		
22 650	Ref. No. 42		
32 300	Ref. No. 43		
14 300	Ref. No. 44		
27 750	Ref. No. 45		
23 000	Ref. No. 46		
16 300	Ref. No. 47		
18 400	Ref. No. 48		
15 600	Ref. No. 49		

## EFFECT OF TEMPERATURE AND OF DIFFERENT FIRING TEMPERATURES

Volts per mm	Temp.	Type	Remarks	Lit.	
11 380 375	24 274	Composition 49 % mixed clays, 16 % flint, 35 % feld- spar. Fired at cone 9 (all American materials)	Tested in elec. furnace	(48)	
17 700	25				
16 600	100				
7 200	200				
	790	Ref. No. 88	Test pieces were small cups (jiggered) 5½ in. high, 3 in. diam., 0.15 in. thick. At 325° all four bodies became conductors, though still offering high resistance	(152)	
17 450	25				
16 550	100				
6 560	200				
	920	Ref. No. 86			
16 800	25				
16 250	100				
7 750	200				
	1 840	Ref. No. 74			
17 600	25				
16 400	100				
6 950	200				
	1 310	Ref. No. 76			
13 550	300				
13 470					
14 660		Composition 59 % mixed clays, 18 % flint, 23 % feldspar	Fired quickly to cone 10; cooled slowly Fired quickly to cone 13; cooled to cone 02 in. one hour; then slowly	(86)	
			Fired quickly to cone 10; then slowly to cone 12; quickly to cone 17; cooled slowly		
12 850			Fired quickly to cone 10; then slowly to cone 13 and fired 20 hr; cooled quickly to cone 2 and then slowly	(86)	
13 560		Composition as above but with soda-feldspar instead of potash-feldspar	Fired like the foregoing Other bodies of different compositions gave simi- lar results		
14 820					
14 100					
13 860					

## EFFECT OF TEMPERATURE AND OF DIFFERENT FIRING TEMPERATURES.—(Continued)

Volts per min	Temp.	Type	Remarks	Lit.
25 400	14	Ref. No. 42	Test pieces were the cups described above	(144)
18 000	104			
5 030	150			
1 620	213			
1 020	248			
1 040	310*			
520	325*			

\* After prolonged application of pressure. Two curves are given (30) showing the current-time effects of the application of a potential of 584 volts (from a storage battery) to porcelain test-pieces heated to 530°. For other tests of dielectric strength of various trial bodies refer to (6, 71, 145).

## VELOCITY OF SOUND

Velocity km/sec	Type	Lit.	Velocity km/sec	Type	Lit.
5.93	Rosenthal laboratory porcelain	(113, 123)	4.9-5.2	Porcelain in general	(32, 113, 123)
6.68	Rosenthal special trial porcelain 6048	(113, 123)	3.6	Bad porcelain	(32, 113, 123)
5.05	Hermisdorf hard porcelain	(29, 113)			

The velocity of transmission of sound vibrations depends on the modulus of elasticity of the material. Hence the tone given by porcelain when struck is a function of the velocity of sound, and from such tones may be obtained indications of the quality of the porcelain.

## TRANSLUCENCY OF PORCELAIN

For methods and results, v. (65, 74, 77, 81, 133, 151).

## LITERATURE

(For a key to the periodicals see end of volume)

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## REFRACTORY MATERIALS

GORDON B. WILKES

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TYPICAL COMPOSITIONS, % BY WEIGHT

Materials	Al <sub>2</sub> O <sub>3</sub>	CaO	Fe <sub>2</sub> O <sub>3</sub>	MgO	SiO <sub>2</sub>	Others	Lit.
Alundum.....	92-99						(72)
Bauxite brick...	65-95		3-8		5-13	TiO <sub>2</sub> , 1-7	(34)
Carborundum brick.....	0-5		0-1		0-5	SiC, 90-100	(28, 34)
Chrome brick...	14-20	Trace	14-19	11-17	3-10	Cr <sub>2</sub> O <sub>3</sub> , 36-46	(34)
Fire clay brick...	15-45	0-0.7	0-6	0-0.7	40-75	Alkalies, 0-2	(13, 34, 36, 84)
Magnesite brick.	0-4	0-6	0-10	80-94	0-11	TiO <sub>2</sub> , 0-2.8	(34, 47, 54)
Silica brick.....	0-2	0-6	0-2	0-0.8	90-98	Alkalies, 0-0.6	(24, 35, 40, 49, 53, 70, 86)
Zirconia brick...						ZrO <sub>2</sub> , 75-95	(74, 34, 28, 8)

BULK DENSITY AND SPECIFIC GRAVITY

	Bulk density g/cm <sup>3</sup>	True sp. gr.	Lit.
Alumina, Al <sub>2</sub> O <sub>3</sub> .....		{ α3.93-4.01 β3.03± 0.01	(62, 68)
Alundum.....	2.6	3.02-4.00	(48, 34)
Bauxite brick.....		3.15-3.25	(34, 11)
Carborundum, SiC..		3.12-3.20	(80)
SiC brick.....	2.05-2.60	(25, 80)	
Chrome brick.....	2.8-3.2	3.90-4.00	(80, 34)
Fire clay brick.....	1.7-2.1	2.1-2.8	(34, 84, 18, 25)
Magnesium oxide (MgO).		{ α3.2 β3.67-3.69	(81, 55)
Magnesite brick....	2.0-2.8	3.1-3.6	(80, 55, 34, 18, 54)

BULK DENSITY AND SPECIFIC GRAVITY.—(Continued)

	Bulk density g/cm <sup>3</sup>	True sp. gr.	Lit.
Silica, fused.....	{ 2.22 (transparent) 2.07 (translucent)		(41)
Quartz, SiO <sub>2</sub> .....		2.646-2.656	(48, 14)
Tridymite, SiO <sub>2</sub> ....		2.31-2.32	(48)
Cristobalite, SiO <sub>2</sub> ..		2.32-2.41	(48, 14)
Silica, amorphous...		2.04-2.21	(48)
Silica brick.....	1.50-1.88	2.05-2.75	(70, 34, 18, 42, 29, 53, 86, 84)
Zirconia, ZrO <sub>2</sub> .....		5.48-5.90	(48, 66, 74, 8)
Zirconia brick.....		4.55-5.00	(58, 74)
Carbon.....		1.7-2.0	(48)
Graphite.....		2.17-2.32	(48, 18)

POROSITY

Material	Porosity, %	Lit.
Bauxite brick.....	46-50	(38)
Carborundum brick.....	17-34	(25)
Fire clay brick.....	20-30	(37, 84)
Magnesite brick.....	24-40	(42)
Silica brick.....	18-43	(70, 38, 42)
Zirconia brick.....	19	(58, 74)



CRUSHING STRENGTH, MEGADYNE  $\text{cm}^{-2}$   
 $1 \text{ megadyne cm}^{-2} = 14.5 \text{ lb. in.}^{-2} = 1020 \text{ g cm}^{-2}$

	20°C	800°C	1000°C	1300°C	1500°C	Lit.
Bauxite brick*.....	390-650	260-350	670-700	54-93	15	(4)
Carborundum*.....	407	417	574	147	69	(4)
Chrome brick*.....	442	442	417	211	74	(4)
	252		116	5.8	1.9	(51)
Fire clay brick*....	191-1090	123-544	103-740	113-726	20-64	(4, 51, 84, 87)
	70-300	60-300	70-250	20-120	0-20	
Magnesite brick*...	441	201	186	152	29	(4, 51, 54)
	140-600		82	64	3.5	
Silica (fused)*.....	2500	1020	765	164	98	(4)
Silica brick.....	150-200	90-170	70-160	60-110	20-80	(4, 51, 54, 57, 29, 70)
Zirconia*.....	388	270	338	88	9.8	(4)

\* Values given by Bodin, probably high for standard brick. Test specimens were 2 cm cube.

## FUSION TEMPERATURE

	°C	Lit.
Alumina, $\text{Al}_2\text{O}_3$ .....	2010-2050	(8, 48)
Alundum.....	1750-2000	(79, 72)
Bauxite clay.....	1750-2000	(84, 35)

## FUSION TEMPERATURE.—(Continued)

	°C	Lit.
Bauxite brick.....	1565-1785	(44, 45)
Carborundum.....	2200-2240 d	(82, 8, 21, 72)
Chromium oxide, $\text{Cr}_2\text{O}_3$ .....	1990	(44)
Chrome brick.....	1850-2050	(44, 54, 45, 48)
Fire clay brick.....	1500-1750	(44, 34, 40, 39, 45, 84)
Magnesium oxide, $\text{MgO}$ .....	2800	(8)
Sintered magnesia.....	2200-2600	(84, 10)
Magnesite brick.....	2150-2165	(54, 12, 44)
Silica, $\text{SiO}_2$ .....	1700-1710	(8, 44, 48)
Silica brick.....	1685-1800	(29, 19, 38, 48, 12, 40, 44, 45)
Mullite ("sillimanite"), $(\text{Al}_2\text{O}_3)_3$ - $(\text{SiO}_2)_2$ .....	1816	(15)
Spinel, $\text{MgO}.\text{Al}_2\text{O}_3$ .....	2135	(68)
Zirconia, $\text{ZrO}_2$ .....	2500-2950	(8, 71, 1, 83)
Zirconia brick.....	2000-2600	(8, 71, 1, 74)

## TEMPERATURE OF FAILURE UNDER LOAD

Load =  $34.5 \times 10^5 \text{ dyne cm}^{-2} = 50 \text{ lb. in.}^{-2} = 3520 \text{ g cm}^{-2}$

Material	Alundum brick	Bauxite brick	Carbo- rundum	Chrome	Fire clay	Magnesite brick	Silica	Zirconia brick
Temp. °C.....	1550+	1350	1650+	1400-1450	1250-1500*	1410-1555	1600-1650	1510
Remarks.....	No failure	Softens	No failure	Shears	Softens	Shears	Shears	Softens
Lit.....	(7)	(69, 7)	(52, 25)	(7, 35)	(84, 3, 19, 35)	(7)	(7, 25, 19)	(7)

\* Load = 25 lb. in.<sup>-2</sup>.

MEAN LINEAR COEFFICIENT OF THERMAL EXPANSION BETWEEN  $t^\circ\text{C}$  AND  $25^\circ\text{C}$ 

$$k = \frac{1}{l_{25}} \frac{l_t - l_{25}}{t - 25} = A \times 10^{-6}$$

	Variation	A				Lit.
		100°C	500°C	1000°C	1500°C	
Alumina, $\text{Al}_2\text{O}_3$ .....	7.2-8.0 between 900°C and 25°C					(79)
Alundum.....		7.1-8.5				(79, 72)
Bauxite brick.....		4.4	5.2	5.3	5.3	(84)
Carborundum, $\text{SiC}$ .....	$\left\{ \begin{array}{l} 4.38(800-700^\circ\text{C}) \\ 2.98(900-800^\circ\text{C}) \end{array} \right\}$	6.58		4.35		(43)
SiC brick.....	6.0(1300-25°C)		5.2	5.8		(84)
Chrome brick.....				9.0	1.1	(48, 78)
Fire clay brick.....		8.1 ± 3.0	7.5 ± 3.0	6.7 ± 3.0	5.9 ± 3.0	(84, 78, 63, 55)
Mag. oxide, $\text{MgO}$ .....	$\left\{ \begin{array}{l} 11.5-13.1 \\ (300-25^\circ\text{C}) \end{array} \right\}$	9.7-11.4				(23, 84)
Magnesite brick.....		11.5 ± 1.0	11.7 ± 2.0	12.4 ± 1.5	13.5 ± 1.0	(78, 54, 64, 50, 65, 48)
Silica brick.....	36 ± 3(200-25°C)	28 ± 3	22 ± 5	13 ± 2	8.6 ± 1	(78, 29, 77, 55, 53, 70, 84, 48)
Zirconia (fused), $\text{ZrO}_2$ .....		8.4				(8)
Carbon.....			1.5-5.5			(84, 48)
Graphite.....	7.8(40-25°C)					(48)

For mean coefficient between any two temperatures,  $\alpha_m = \frac{\alpha_{t_1}(t_1 - 25) - \alpha_{t_2}(t_2 - 25)}{t_1 - t_2}$ , where  $\alpha_{t_1}$  and  $\alpha_{t_2}$  may be taken from a graph.

## EXPANSION AND CONTRACTION DURING HEATING

The data given in Figs. 1-4 and in the table below record the % changes in length undergone by  $1 \times 1 \times 9$  in. test bars when heated in a gas fired muffle furnace with neutral atmosphere at the rate of  $100^\circ\text{C}$  per hour. Specimens marked "brick" are commercial products. For compositions of these and methods of preparing all specimens, *v.* the original (88).

No.	Type	M. P.,* $^\circ\text{C}$	Fired to, $^\circ\text{C}$	$\frac{10^7\Delta l}{l\Delta t}$ 0° to $t_s$	$t_s^\dagger$ $^\circ\text{C}$
1	Silica brick.....	1700		83	1550
2	Kaolin.....	1740	1300	47	1050
3	Kaolin.....	1740	1430	68	1380
4	Kaolin.....	1740	1500	53	1580
5	Kaolin.....	1740	1620	43	1610
6	Fire clay brick (Mo.)...	1720		54	1300
7	Fire clay brick (Pa.)....	1680		51	1250
8	Fire clay brick (Colo.)..	1700		54	1220
9	Fire clay brick (Md.)...	1610		45	1100
10	SiC brick.....	>2000		43	>1700
11	Zircon white.....	>2000	1650	64	1510
12	Zircon brown.....	1935	1590	42	1550
13	ZrO <sub>2</sub> .....	>2000	1675	59	1600
14	Mullite.....	1850	1785	53	>1700
15	Magnesite.....	>2000	1680	142	>1700
16	Magnesite brick.....			147	1440
17	Chrome brick.....			104	1540
18	Mg-spinel.....	>2000	1690	76	1600
19	Lime.....	>2000	1740	138	>1700
20	Fused Al <sub>2</sub> O <sub>3</sub> .....	>2000	1650	77	1580
21	Infusorial-earth brick...	1630		74	1050

\* Reducing atm.

† Beginning of shrinkage or expansion.

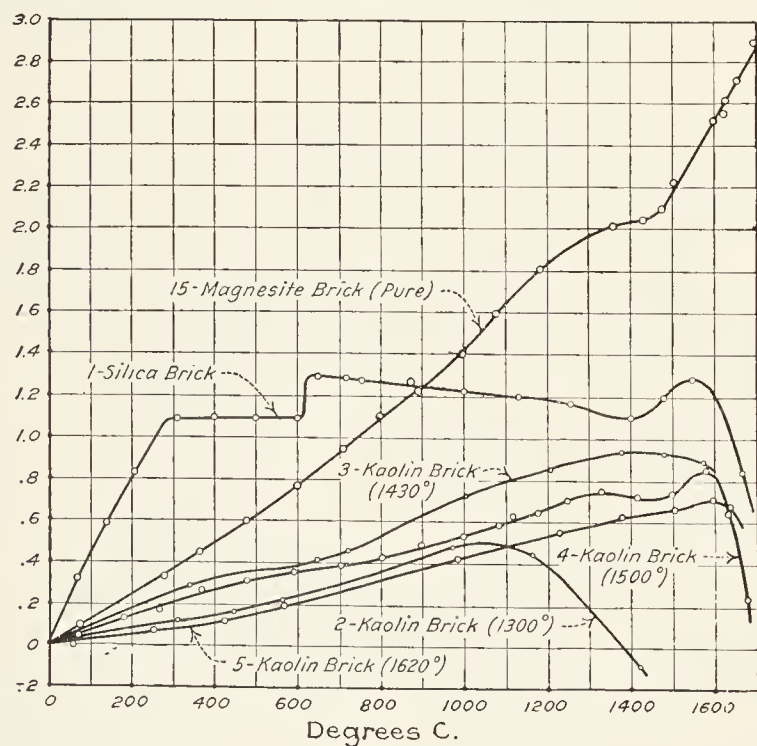


FIG. 1.

Figure 5 shows a comparison of the expansion of German and American silica brick. Curves 1, 2 and 3 are for American silica brick (measurements reported by the National Bureau of Standards); Curves I, II and III, for German silica brick (measurements by Endell and Steger, *Glastech. Ber.*, 4; May, 1926).

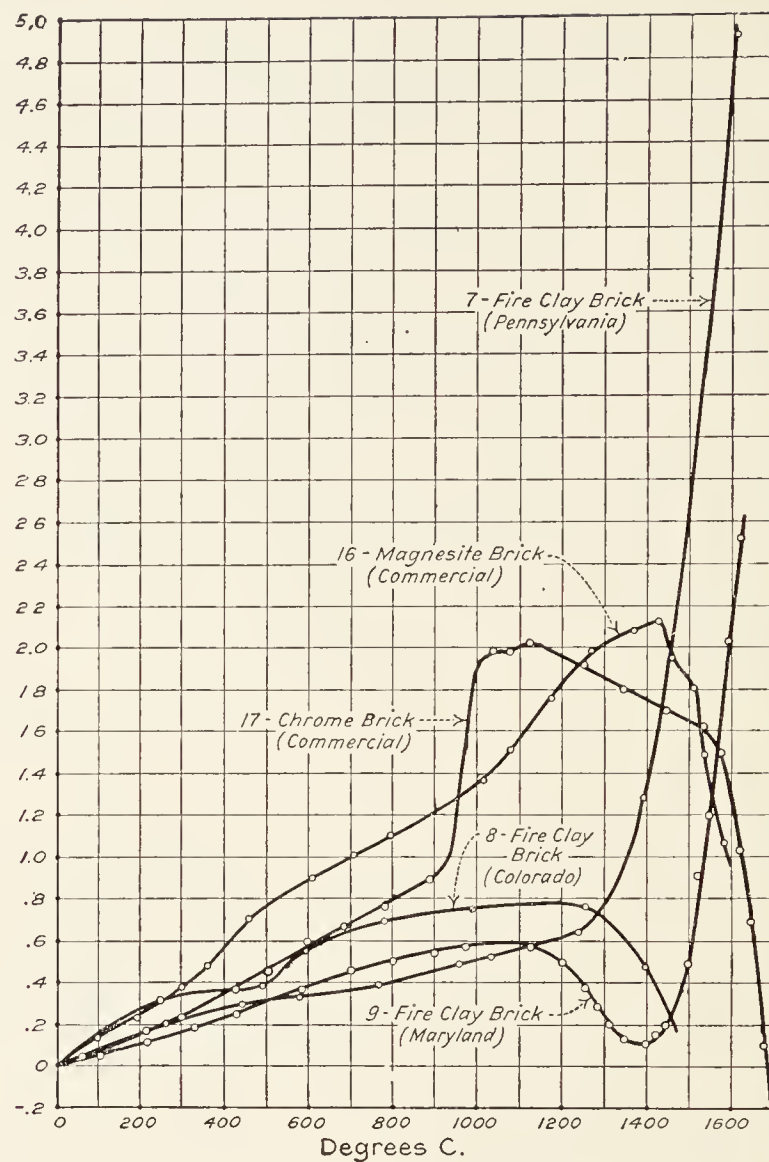


FIG. 2.

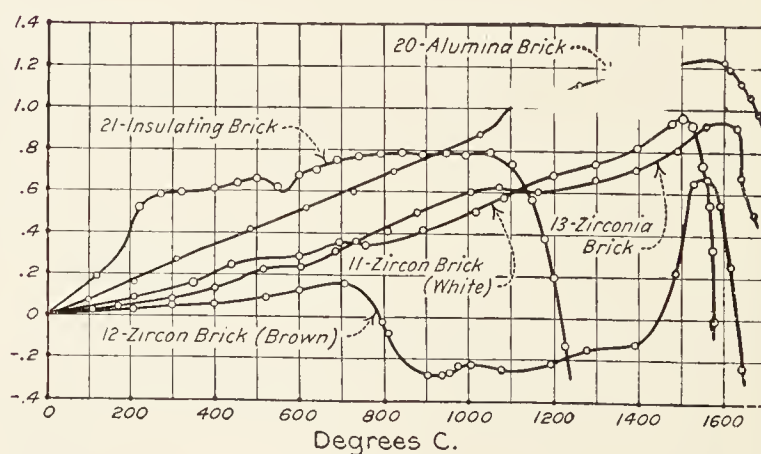


FIG. 3.



MEAN SPECIFIC HEAT BETWEEN  $t^\circ$  AND  $25^\circ\text{C}$ 

Joule per gram per  $^\circ\text{C}$   
 $1 \text{ joule g}^{-1} \text{ per } ^\circ\text{C} = 0.239 \text{ g-cal g}^{-1} \text{ per } ^\circ\text{C} = 0.239 \text{ BTU lb.}^{-1} \text{ per } ^\circ\text{F}$

	100 $^\circ\text{C}$	500 $^\circ\text{C}$	1000 $^\circ\text{C}$	1500 $^\circ\text{C}$	Lit.
Alumina, $\text{Al}_2\text{O}_3$ .....	0.837	1.00	1.09	1.15	(84)
Alundum.....	0.778				(79)
SiC brick.....	$0.838 \pm 0.13$		$0.78 \pm 0.17$		(79, 33, 18)
Chrome brick.....	0.71	0.84	0.92		(78)
Fire clay brick.....	$0.83 \pm 0.04$	$0.93 \pm 0.04$	$1.08 \pm 0.04$	$1.25 \pm 0.04$	(78, 5, 85, 18, 31)
Mag. oxide, MgO.....	$0.98 \pm 0.02$	$1.09 \pm 0.02$	$1.17 \pm 0.02$	$1.21 \pm 0.02$	(84, 48, 54)
Magnesite brick.....	$0.93 \pm 0.04$	$1.05 \pm 0.04$	$1.16 \pm 0.04$	$1.24 \pm 0.04$	(32, 76, 84, 78, 18)
Silica brick.....	$0.84 \pm 0.06$	$0.95 \pm 0.06$	$1.10 \pm 0.06$	$1.24 \pm 0.06$	(5, 32, 76, 84, 61, 78, 18)
Zirconium oxide.....	$0.46 \pm 0.02$	0.55	0.66	0.75	(5, 8)
Carbon.....	0.516	2.0 at 2000 $^\circ\text{C}$	1.3		(16)
Graphite.....		2.2 at 2000 $^\circ\text{C}$	1.23	1.71	(16, 46)

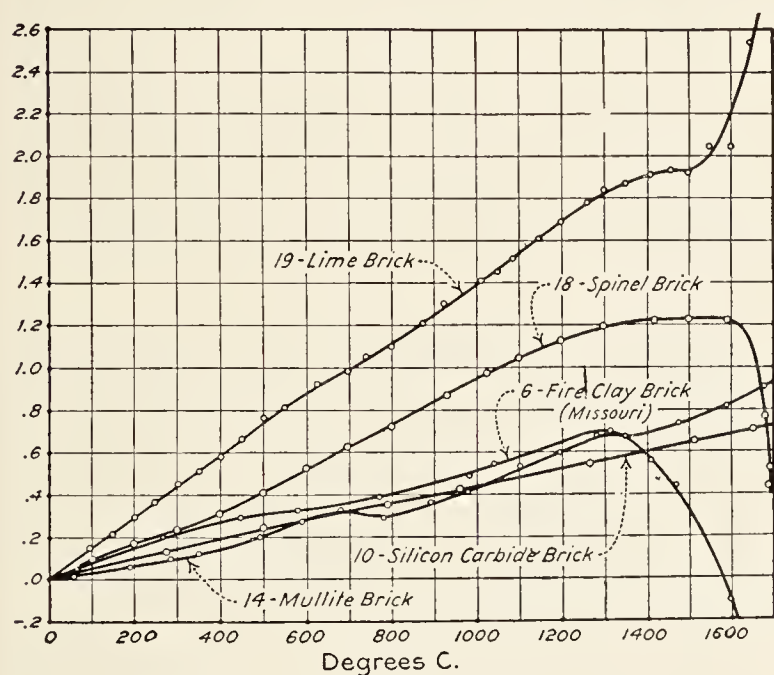


FIG. 4.

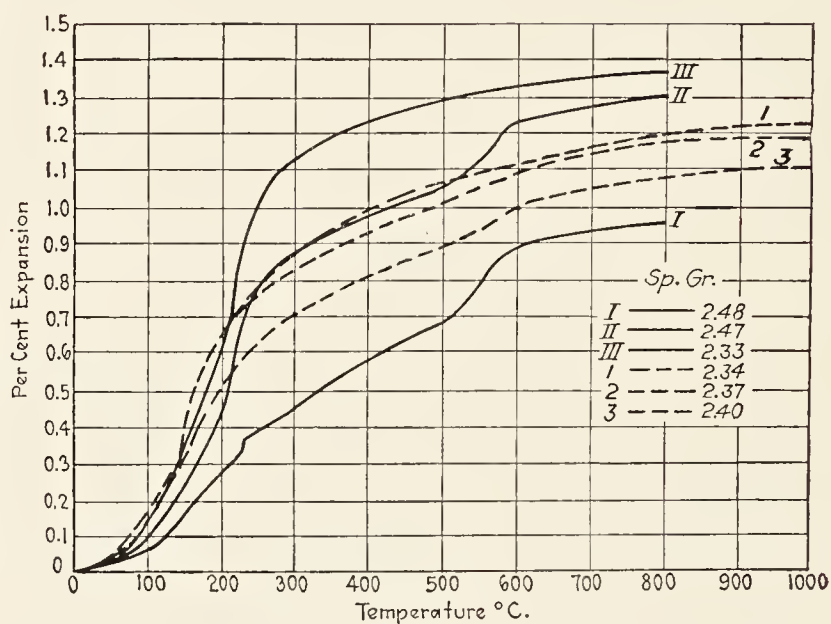


FIG. 5.

MEAN COEFFICIENT OF THERMAL CONDUCTIVITY BETWEEN  $t^\circ$  AND  $25^\circ\text{C}$ 

Joule  $\text{cm}^{-2} \text{ sec}^{-1} (^\circ\text{C, cm}^{-1})^{-1}$   
 $1 \text{ joule cm}^{-2} \text{ sec}^{-1} (^\circ\text{C, cm}^{-1})^{-1} = 0.239 \text{ g-cal cm}^{-2} \text{ sec}^{-1} (^\circ\text{C, cm}^{-1})^{-1} = 0.193 \text{ BTU ft.}^{-2} \text{ sec}^{-1} (^\circ\text{F, in.}^{-1})^{-1}$

	100 $^\circ\text{C}$	500 $^\circ\text{C}$	1000 $^\circ\text{C}$	1500 $^\circ\text{C}$	Lit.
Alundum.....	0.035 between 1250 $^\circ\text{C}$ and 650 $^\circ\text{C}$				(62, 67)
Bauxite brick.....	0.0046		0.0064		(6)
SiC bonded brick.....			0.08-0.10		(18, 86, 79)
Chrome brick.....			0.024		(86)
Fire clay.....	$0.0065 \pm 0.0015$	$0.0089 \pm 0.0015$	$0.0117 \pm 0.0015$	$0.0143 \pm 0.0020$	(18, 22, 17, 84, 25, 31, 86)
Magnesite bonded brick, elec. sintered..	$0.041 \pm 0.009$	0.048	$0.047 \pm 0.020$		(84)
Silica brick.....	$0.0080 \pm 0.0010$	$0.0096 \pm 0.0010$	$0.0121 \pm 0.0010$		(18, 22, 17, 84, 86)
Carbon.....	0.38 at 360 $^\circ\text{C}$	0.45	0.55	0.58	(30)
Graphite.....	1.41 at 390 $^\circ\text{C}$	1.38	1.19	1.15	(30)

For mean coefficient between any two temperatures,  $k_m = \frac{k_{t_1}(t_1 - 25) - k_{t_2}(t_2 - 25)}{t_1 - t_2}$  where  $k_{t_1}$  and  $k_{t_2}$  may be taken from a graph.

## ELECTRICAL RESISTIVITY

	Megohm-cm <sup>3</sup>	Ohm-cm <sup>3</sup>				Lit.
	25°C	1000°C	1200°C	1400°C	1500°C	
Alundum.....		1.8 × 10 <sup>6</sup>				(79)
Diaspore.....	137		193 000		2 500	(28)
Bauxite brick.....	133	17 200	6 100	2 200	1 100	(27)
Carborundum.....		3.7	1.3	0.65		(80)
Carborundum refrax brick.....	107 × 10 <sup>-6</sup>	4.1	2.5	1.74	1.62	(27)
Carborundum 95 % SiC bonded.....	107 × 10 <sup>-3</sup>	4 720	4 160	1 435	745	(27)
Carborundum 90 % SiC bonded.....	127	197 000	29 500	10 100	8 590	(27)
Chrome brick.....	48.1	171	63	85	41	(27)
		420	450	320		(75)
Fire clay brick.....	137	10 800	4 160	1 420	890	(27)
		6 600	480 000	180 000	80 000	(84)
			2 300	690	280	(75)
Magnesite brick.....	137	708 000	193 000	22 400	2 500	(27)
			100 000	40 000	3 000	(84)
			12 000	400		(60)
Silica (fused).....	5 × 10 <sup>12</sup>	4 × 10 <sup>4</sup> at 727°C				
Silica brick.....	125	300 000	62 000	16 500	8 420	(27)
			360 000	125 000	63 000	(84)
				2 400	710	(75)
Zirconia brick.....	134	131 300	1 230			(56)
			1 250	300		(1)
			7 710	968	412	(27)
Zirconia.....			12 × 10 <sup>7</sup>			(8)
Carbon.....	46 × 10 <sup>-10</sup>	3.7 × 10 <sup>-3</sup>	3.7 × 10 <sup>-3</sup>	3.7 × 10 <sup>-3</sup>	3.6 × 10 <sup>-3</sup> at 2000°C	(30)
Graphite.....	85 × 10 <sup>-11</sup>	7.95 × 10 <sup>-4</sup>	7.9 × 10 <sup>-4</sup>	7.9 × 10 <sup>-4</sup>	7.9 × 10 <sup>-4</sup> at 2000°C	(30)

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## ABRASIVE MATERIALS

M. L. HARTMANN

## COMMON AND TRADE NAMES

IND. NO.

- Aluminium oxide (fused, impure) ("aloxite," "alundum," "lionite," "borolon," "alumo"). Al<sub>2</sub>O<sub>3</sub>
- Corundum. Al<sub>2</sub>O<sub>3</sub>
- Diatomaceous earth (infusorial earth, kieselguhr, fossil flour, fossil meal, tripolite, diatomite, polerschiefer, desmid earth, molera, white peat, tellurine, randanite, ceyssatite, bergmehl, radiolarian earth). SiO<sub>2</sub>

- Emery.
- Flint. SiO<sub>2</sub>
- Garnet (almandite, rhodolite).
- Glass (alkali lime).
- Pumice (pumicite, santorini, santorine earth).
- Silicon carbide ("carborundum," "crystolon," "carbolon.") SiC

For diamond, iron oxides, iron alloys and quartz. *see* other sections of I. C. T.



Ind. No.	Hardness Mohs' scale	Density g/cm <sup>3</sup>	Thermal expansion $\frac{10^6}{l} \frac{dl}{dt}$ per °C	Thermal conductivity $k = 10^{-6} \times A \text{ g-cal cm}^{-2} \text{ sec}^{-1} (\text{°C, cm}^{-1})^{-1}$ A
1	9+ (25)	3.93-4.00 (3, 25)	8.7 (25-900°C) (2) 7.7 (0-1580°C) (17)	
2	9 (1, 4, 10, 11, 21)	3.95-4.10 (1, 4, 10, 21)	6.76 (19)	
3	1-1.5 (10)	2.1-2.2 (10)		227 (200°C) (10) 315 (800°C)
4	7-9 (10)	3.75-4.35 (4)		
5	7 (4, 10)	2.61-2.63 (26)	17.4 (15-1000°C) (7)	
6	6.5-7 (10), cf. (1, 16)	3.4-4.3 (10), cf. (1, 16)		
7		2.4-2.6 (14)	8.01-11.88 (15)	1080-2270 (18)
8	6 (10)	2.5 (10)		
9	9-10 (9, 22)	3.17-3.21 (3, 5)	4.74 (100-900°C) (2) 4.3 (0-1700°C) (9)	43000 (1350°C) (6) (34 % porosity)

Compressibility  $\frac{dV}{VdP}$  ( $P$  in atm.) =  $3.8 \times 10^{-7}$  for No. 2 (12);

$2.2 \times 10^{-7}$  for No. 9 (100-500 atm.) (24).

Specific heat in g-cal/g = 0.1976 (8-98°C) for No. 2 (23); 0.212-0.236 (133-405°C) for No. 7 (8); 0.186 (31-98°C) for No. 9 (20), cf. (13, 27).

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(For a key to the periodicals see end of volume)

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## PROPERTIES OF GLASS

GEORGE W. MOREY

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The "Index Nos." of Table 1 are identification numbers by means of which the glasses are identified in the property tables which follow.

TABLE 1.—GLASS COMPOSITIONS

With the exception of those glasses whose index numbers are in italics, all the compositions listed below are calculated from the ingredients melted to produce the glass type (so-called "batch" compositions). The glasses actually measured will therefore differ from the compositions given by unknown amounts; a difference in optical properties between the types of Table 1 and like numbered glasses in subsequent tables indicates such uncontrolled variations. The analyses of similar types shown in Table 1 give an idea of the magnitude of the difference to be expected. In the tables which follow, this uncertainty as to the actual glass composition is usually greater than that introduced by errors in measurement.

The numbers under "Glass Types" in Table 1 represent  $(n_D - 1)10^3/10\nu$ ; in which  $\nu = \frac{n_D - 1}{n_F - n_C}$ . Glasses 1-114 are arranged in the order of increasing  $n_D$ ; glasses 115-133, in order of decreasing  $\text{SiO}_2$  content; glasses 134-146 in order of decreasing  $n_D$ .

Les nombres index de la Table 1 sont des nombres d'identification au moyen desquels les verres sont identifiés dans les tables des propriétés qui font suite.

TABLE 1.—COMPOSITIONS DES VERRES

A l'exception des verres dont les nombres index sont en italique, toutes les compositions indiquées ci-dessous sont calculées à partir des substances de départ entrant dans la fabrication du verre type. La composition réelle des verres dont on donne les mesures peut donc différer des compositions indiquées par un montant inconnu; une différence dans les propriétés optiques entre les types de la Table 1 et les verres de même numéro dans les tables subséquentes met en évidence ces variations incontrôlées. Les analyses de types similaires indiquées dans la Table 1 donnent une idée de l'ordre de grandeur de la différence à laquelle on peut s'attendre. Dans les tables qui suivent, cette incertitude en ce qui concerne la composition réelle du verre est ordinairement plus grande que celle introduite par des erreurs dans les mesures.

Les nombres dans "Verres types" dans la Table 1 représentent  $(n_D - 1)10^3/10\nu$ ; dans laquelle  $\nu = \frac{n_D - 1}{n_F - n_C}$ . Les verres 1 à 114 sont disposés dans l'ordre de  $n_D$  accroissant; les verres 115 à 133 dans l'ordre de la teneur décroissante en  $\text{SiO}_2$ ; les verres 134 à 146 dans l'ordre de  $n_D$  décroissant.

Die Indexnummern der Tafel 1 sind Erkennungszahlen mit Hilfe deren die Gläser in den folgenden Eigenschaftstabellen identifiziert sind.

TAFEL 1.—GLAS-ZUSAMMENSETZUNGEN

Mit Ausnahme bei jenen Gläsern deren Indexnummern kursiv geschrieben sind, ist ihre folgende Zusammensetzung aus den Bestandteilen berechnet, die zur Erschmelzung des Glases verwendet worden sind (Glasatz). Die wirkliche Zusammensetzung des Glases wird deshalb von der angegebenen in unbekanntem Ausmasse abweichen. Ein Unterschied in den optischen Eigenschaften der Glas-typen in der Tafel 1 und denen in den folgenden Tabellen, welche ähnlich bezeichnet sind, zeigt solche unkontrollierbare Veränderungen. Die Analyse ähnlicher Glassorten, welche in der Tabelle 1 verzeichnet sind, geben eine Vorstellung von der Grösse der Abweichungen die zu erwarten sind. In den folgenden Tabellen ist die Unsicherheit bezüglich der wirklichen Glaszusammensetzung gewöhnlich grösser, als sie durch Messfehler verursacht werden kann.

Die Zahlen unter "Glass Types" in der Tafel 1 bedeuten  $(n_D - 1)10^3/10\nu$  wobei  $\nu = \frac{n_D - 1}{n_F - n_C}$  ist. Die Gläser 1-114 reihen sich nach aufsteigenden  $n_D$ -Werten, Gläser 115-133 nach absteigendem  $\text{SiO}_2$ -Gehalt und Gläser 134-146 nach absteigenden  $n_D$ -Werten.

I numeri indici della Tabella 1 sono numeri di identificazione a mezzo dei quali si possono individuare i diversi vetri nelle tabelle delle proprietà.

TABELLA 1.—COMPOSIZIONE DEI VETRI

Fatta eccezione per i vetri con numero indice scritto in corsivo, per tutti gli altri le composizioni riportate sono quelle che si calcolano dalle quantità dei componenti messe a fondere assieme.

Le composizioni effettive differiscono perciò da quelle indicate di una quantità sconosciuta; ed eventuali differenze nelle proprietà ottiche dei vetri della Tabella 1 e di quelli delle tabelle successive contraddistinti da uno stesso numero stanno a dimostrare appunto queste incontrollabili variazioni. Le analisi di tipi simili di vetri riportate nella Tabella 1, danno una idea della grandezza delle differenze che possono aversi. La incertezza intorno alla composizione effettiva del vetro è, in genere, maggiore di quella che può essere dovuta ad errori di misura.

I numeri sotto la dicitura "Glass Types" nella Tabella 1 rappresentano  $(n_D - 1)10^3/10\nu$ ;

dove  $\nu = \frac{n_D - 1}{n_F - n_C}$ . I vetri da 1 a 114 sono disposti in ordine accrescente di  $n_D$ ; i vetri da 115 a 133 in ordine decrescente del contenuto di  $\text{SiO}_2$ ; i vetri da 134 a 146 in ordine decrescente di  $n_D$ .



Ind. No.	Type	Name	Lit.	SiO <sub>2</sub>	B <sub>2</sub> O <sub>3</sub>	Na <sub>2</sub> O	K <sub>2</sub> O	CaO	BaO	ZnO	PbO	MgO	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	Mn <sub>2</sub> O <sub>3</sub>	Sb <sub>2</sub> O <sub>3</sub>	As <sub>2</sub> O <sub>3</sub>	As <sub>2</sub> O <sub>5</sub>	Cl	SO <sub>2</sub>	H <sub>2</sub> O	Table No.
1	475/636	Pyrex laboratory	(12)	80.75	12.00	4.10	0.10	0.30														2, 5, 11a, 11b, 11c, 12a, 17a
1a		Pyrex radio																				2, 11c
2	479/702	Chance, fluor crown*	(9)	54.8	18.7		20.3															11a, 11c, 13c
3	496/644	Schott, borosilicate crown	(66)	71.1	14	10																2, 4, 5, 7, 9, 11c
4	494/646	Schott, borosilicate crown	(55)	69.59	14	8	3.0															10, 13
5	498/653	Chance, borosilicate crown	(9)	59.5	21.5		14.4	0.3		2.3												2, 7, 12b
6	500/647	Schott, borosilicate thermometer	(66)	72	12	11.0																
6a		Same, analysis	(43)	72.86	10.43	9.82	0.10	0.35														
7	506/602	Schott, crown	(68)	74.6		9.0	11.0	5.0														2, 4
8	508/604	Schott, Jena geräte	(48)	64.7	10.9	7.5	0.37	0.63														7, 12b
9	509/641	Chance, borosilicate crown	(9)	69.6	6.7	20.5	2.9															13
10	510/621	Chance, borosilicate crown	(9)	71.1	2.7	18.8	6.8															13
11	510/	Schott, silicate crown	(35)	69.15	1.0	6.5	15.0															10
12	511/640	Schott, borosilicate crown	(68)	70.4	7.4	5.3	14.5	2.0														2, 4, 5, 7, 10, 12b, 14, 17a, 17b
12a		Same, E. T. Allen, analyst	(3)	72.15	5.88	5.16	13.85	2.04	0													
13	511/605	Schott, borosilicate crown	(68)	68.1	3.5	5.0	16.0															7
14	513/637	Schott, borosilicate crown	(68)	68.2	10.0	10.0	9.5															2, 15
15	513/573	Schott, zinc silicate crown	(66)	70.6		17.0																2, 4, 11b
16	515/579	Chance, zinc crown	(9)	69.7		11.0	1.7	0.4														13
17	516/640	Schott, borosilicate crown, analysis	(3)	69.58	9.91	8.44	8.37	0.07	2.54	0												5, 7, 9, 11a, 11c
18	516/638	Chance, borosilicate crown	(9)	67.1	7.2		16.2	2.0	7.2													13
19	516/620	Borosilicate crown	(1)	67	12	9	8		4													6, 16
20	516/608	Chance, hard crown	(9)	69.5			19.0	11.1														13
21	516/536	Schott, borosilicate crown	(68)	53.5	20.0		6.5															2
22	517/609	Schott, borosilicate crown	(68)	69.0	2.5	4.0	16.0	8.0														2, 4, 7, 11c
23	517/602	Schott, silicate crown	(66)	64.6	2.7	5.0	15.0															2, 4, 7, 12b, 15, 17a
24	517/559	Schott, silicate crown																				5, 7, 14
25	517/558	Schott, light barium crown	(53)	65.4	2.5	5.6	15.0															14, 17c
26	518/609	Bureau of Standards, light crown	(48)	68.6	3.5	12.0	5.0															7
27	518/605	Chance, hard crown	(9)	69.6			18.4	11.5														13
28	518/599	Bureau of Standards, light crown	(48)	67.0	3.5	12.0	5.0															7
29	519/603	Chance, hard crown	(9)	72.0		6.1	10.1	11.4														13
30	520/618	Bureau of Standards, borosilicate crown	(48)	66.5	7.8		5.9															7
31	520/520	Schott, high dispersion crown	(53)	68.7		15.7																11a, 14, 17c
32	522/520	Schott, high dispersion crown	(68)	66.8		16.0																14
33	522/515	Schott, high dispersion crown	(68)	68.2		16.5																5, 7, 11c
34	522/522	E. Posnjak, analyst	(67)	67.40		15.15	0.14	0.39														0.15
35	522/596	Schott, ordinary silicate crown	(35)	62.5	2.0	5.0	15.0															10
36	523/590	Ordinary crown	(1)	73.1		14.0	1.0	12.0														6, 16
37	524/522	Chance, telescope flint	(9)	52.4	18.3	2.3	4.3	0.3														11a, 13
38	522/511	Schott, telescope flint																				11c, 14, 17b
39	527/546	Schott, telescope crown																				14, 17a
40	529/516	Chance, extra light flint	(9)	66.8		9.2	3.9	0.4														13
41	537/512	Schott, borosilicate flint	(30)	35.4	34.3	7.4																11a, 16
42	540/598	Schott, light barium flint	(68)	59.5	3.0	3.0	10.0															14
42a		Same, analysis	(3)	59.13	3.04	3.16	9.70	0.13	19.25	5.00	0											
43	541/596	Chance, light barium crown	(9)	57.1	1.8	4.5	8.5															13
44	541/469	Schott, light flint	(66)	62.6		1	3															12b
45	545/503	Schott, light borosilicate flint	(9)	59.7		5.0	8.0															4, 7, 10, 15, 16
46	547/458	Chance, light flint	(68)	59.3																		13
47	549/461	Schott, extra light flint	(9)	60.6		13.9																5, 7
48	549/455	Chance, light flint	(9)	56.4		12.0																13
49	552/514	Chance, light barium flint	(9)	55.9		13.3																13
50	552/517	Chance, light barium flint	(9)	55.9		13.3																13
51	552/510	Bureau of Standards, barium flint	(48)	58.8	1.7	1.7	8.3															7
52	553/530	Schott, barium flint	(68)	56.2		1.5	11.0															10, 12b, 17a

\* Contains also 7.5 % F

Ind. No.	Type	Name	Lit.	SiO <sub>2</sub>	B <sub>2</sub> O <sub>3</sub>	Na <sub>2</sub> O	K <sub>2</sub> O	CaO	BaO	ZnO	PbO	MgO	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	Mn <sub>2</sub> O <sub>3</sub>	Sb <sub>2</sub> O <sub>3</sub>	As <sub>2</sub> O <sub>3</sub>	As <sub>2</sub> O <sub>5</sub>	Cl	SO <sub>2</sub>	H <sub>2</sub> O	Table No.
53	553/461	Chance, light barium flint.....	7983	(9) 57.7			12.0	0.3	4.5	24.9			0.2				0.3	0.1			13	13
54	561/555	Schott, light barium flint.....	O463	Of unknown composition, but probably differs but little from 58																	5, 7, 14	13
55	563/429	Chance, light flint.....	8653	(9) 55.9			11.1	0.3		32.9			0.2					0.1			13	13
56	568/440	Chance, light barium flint.....	665	(9) 52.3			9.9	0.3	7.4	29.9			0.2					0.2			13	13
57	563/497	Schott, light barium flint.....	O543	(68) 51.6		1.5	9.5			14.0	11.0							0.3			5, 14	5, 14
58	566/550	Chance, light barium flint.....	4469	(9) 49.3		3.2	9.5	0.3	27.2	8.6	0.7		0.2					0.1			11c, 13	11c, 13
59	568/530	Schott, light barium flint.....	O602	(68) 51.2		5.5	5.0		20.0	14.0	4.0							0.3			17b	17b
60	571/430	Schott, light flint.....	O154	(68) 54.3	1.5	3.0	8.0			33.0								0.2			2, 4, 7, 11a, 15, 16	2, 4, 7, 11a, 15, 16
60a		Same, analysis.....		(3) 54.75	0.45	4.31	7.99	0.05	1.64	0.96	29.30	0	0.04	0.02	0			0.14	0.06	0.06	0.20	7, 15
61	572/504	Schott, light barium flint.....	O527	(68) 51.7		1.5	9.5		20.0	7.0	10.0							0.3			2	2
62	573/580	Schott, light barium crown.....	O211	(68) 48.8	3.0	1.0	7.5		29.0	10.3								0.4			2, 4, 5, 11c, 15	2, 4, 5, 11c, 15
63	573/576	Schott, light barium crown.....	O211	(68) 48.1	4.5	1.0	7.5		28.3	10.1								0.1			2, 4, 5, 11c, 15	2, 4, 5, 11c, 15
63a	573/574	Same, E. T. Allen, analyst.....		(67) 47.73	3.90	1.14	7.16	0.15	29.88	8.61			0.02	0.01				0.38	0.03	0.04	0.14	7
64	573/567	Bureau of Standards, barium crown.....		(48) 47.6	4.0	2.0	6.0		29.2	9.9								1.4			6, 16	6, 16
65	573/420	Light flint.....		(1) 54		6	5			35.0								0.6			13	13
66	574/577	Chance, medium barium crown.....	9002	(9) 45.6	4.4		3.9	0.3	32.5	7.9			4.9					0.3			6, 16	6, 16
67	574/570	Light barium crown.....		(1) 47	4	3	5		29	11			1					0.3			14, 17c	14, 17c
68	574/571	Schott, light barium crown.....	O1143	(68) 47.8	4.5	1.0	7.5		28.5	10.3					0.1			0.1			5, 11b, 11c, 12b, 14, 17c	5, 11b, 11c, 12b, 14, 17c
69	575/414	Chance, light flint.....	O1017	(9) 52.8			10.1	0.3			36.5		0.2					0.1			13	13
70	576/408	Schott, light flint.....	O184	(68) 53.7		1.0	8.3				36.6				0.1			0.3			5, 11b, 11c, 12b, 14, 17c	5, 11b, 11c, 12b, 14, 17c
71	579/541	Schott, light barium crown.....	O722	(68) 48.8	3.0	0.8	6.5		21.0	15.5	4.1							0.3			5, 7, 10, 14, 17b	5, 7, 10, 14, 17b
71a	580/538	Same, analysis.....		(3) 45.02	4.50	0.64	6.80		22.39	15.53	4.70		0.09		0			0.55	0.06		0.08	13
72	579/408	Chance, light flint.....	407	(9) 52.5			9.5	0.3		37.5			0.2					0.1			13	13
73	581/442	Schott, ordinary light flint.....	O276	(35) 52.45		4.5	8.0			34.8					0.05			0.2			10, 13	10, 13
74	581/419	Bureau of Standards, light flint.....		(48) 53.9		1.0	7.6	2.0			35.2							0.3			7	7
75	583/469	Schott, light barium flint.....	O578	(68) 49.1		1.0	8.5		13.0	8.5	19.3				0.1			0.5			5, 7, 10, 14, 17b	5, 7, 10, 14, 17b
75a	583/463	Same, E. Posnjak, analyst.....		(3) 49.80		1.24	8.20		13.36	8.03	18.74		0.05	0.01	0			0.51	0.01		0.08	13
76	583/466	Chance, light barium flint.....	466	(9) 47.5		3.0	0.91	0.3	15.3	8.3	16.3		0.2					0.1			13	13
77	584/561	Chance, medium barium crown.....	7472	(9) 42.6	5.1		9.3	0.2	31.4	10.5			0.2					0.8			7	7
78	585/405	Bureau of Standards, light flint.....		(48) 54.0		1.0	6.0	2.0			36.7							0.3			5, 7, 14	5, 7, 14
79	588/611	Chance, dense barium crown.....	9753	(9) 32.3	19.0		0.2	0.2	42.3				5.7					0.5			13	13
80	591/605	Schott, dense barium crown.....	O2122	(68) 37.5	15.0				41.0				5.0					1.5			5, 7, 14	5, 7, 14
81	604/438	Schott, barium flint.....	O1266	(68) 45.2			7.8		16.0	8.3	22.2				0.1			0.4			11a, 17a	11a, 17a
82	606/440	Barium flint.....		(1) 46	6	3	4		15	8	24							0.5			6, 16	6, 16
83	608/570	Dense barium crown.....		(1) 40					43	8			3					0.5			6, 16	6, 16
84	610/574	Schott, heaviest baryta crown.....	O1029	(68) 34.5	10.1				42.0	7.8			5.0		0.1			0.5			2, 5, 11a, 11c, 14, 15, 17a, 17b	2, 5, 11a, 11c, 14, 15, 17a, 17b
85	610/568	Same, analysis.....		(3) 40.17	5.96	0.13	0.03	0.03	42.35	8.17	0		2.79	0.02	0			0.49	0.03		12b	12b
86	612/590	Chance, dense barium crown.....	4873	(9) 36.2	7.7		0.2	0.2	44.6	6.7			3.5					0.7			13	13
87	612/592	Schott, heaviest baryta crown.....	O2071	(68) 31.0	12.0				48.0				8.0					1.0			5, 7, 10	5, 7, 10
88	609/568	Same, analysis.....		(3) 34.56	10.96	0.21	0.09		46.91	1.14	0				0.05			0.55	0.04		13	13
89	613/598	Chance, dense barium crown.....	8065	(9) 31.3	15.4		0.2	0.2	48.7				3.5					0.2			5, 11a, 13	5, 11a, 13
90	613/563	Chance, dense barium crown.....	2065	(9) 36.7	5.9		0.9	0.2	45.1	6.8			3.6					0.8			5, 7, 9, 11a, 11c, 12	5, 7, 9, 11a, 11c, 12
91	613/369	Schott, ordinary silicate flint.....	O118	(68) 46.6		1.5	7.8				43.8							0.3			6, 16	6, 16
91a	614/369	Same, E. T. Allen, analyst.....		(67) 45.64		1.77	8.66	0.05			43.45		0.03					0.22			10, 11a, 11c, 12b, 14, 16, 17b	10, 11a, 11c, 12b, 14, 16, 17b
92	613/369	Chance, dense flint.....	4743	(9) 48.0		5.2	1.2	0.3			45.1		0.2					0.1			13	13
93	613/370	Chance, dense flint.....	3743	(9) 47.5		5.1	1.2	0.3			45.6		0.2					0.1			13	13
94	615/561	Chance, dense barium crown.....	1065	(9) 36.2	4.7		1.8	0.2	45.9	6.7			3.5					0.7			13	13
95	616/370	Medium flint.....		(1) 45		3	4				48							0.4			6, 16	6, 16
96	621/361	Schott, ordinary silicate flint.....	O103	(68) 44.6		0.5	8				46.6							0.3			10, 11a, 11c, 12b, 14, 16, 17b	10, 11a, 11c, 12b, 14, 16, 17b
97	621/361	Chance, dense flint.....	361	(9) 46.3		5.0	1.1	0.3			47.0		0.2					0.1			13	13
98	627/391	Schott, baryta flint.....	O748	(68) 42.8		0.7	7.5		10.8	5.1	32.6							0.5			5, 7, 10, 14, 17a	5, 7, 10, 14, 17a
99	632/357	Schott, ordinary silicate flint.....	O919	(67) 44		1	7				48							0.5			10, 17a	10, 17a
100	645/341	Schott, heavy silicate flint.....	O102	(66) 41			7				51.7				0.1			0.2			2, 4, 5, 16, 17b	2, 4, 5, 16, 17b
100a	649/338	Same, E. Posnjak, analyst.....		(67) 40.99		0.61	6.93	0.13			51.13		0.04	0.02				0.22			0.08	0.08



Ind. No.	Type	Name	Lit.	SiO <sub>2</sub>	B <sub>2</sub> O <sub>3</sub>	Na <sub>2</sub> O	K <sub>2</sub> O	CaO	BaO	ZnO	PbO	MgO	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	Mn <sub>2</sub> O <sub>3</sub>	Sb <sub>2</sub> O <sub>3</sub>	As <sub>2</sub> O <sub>3</sub>	As <sub>2</sub> O <sub>3</sub>	Cl	SO <sub>3</sub>	H <sub>2</sub> O	Table No.
101	647/337	Chance, extra dense flint.....	337	(9) 40.6		0.5	7.5	0.2			51.5		0.2					0.1				13
102	630/322	Schott, heavy silicate flint.....	O102	(53) 40.0			6.5				52.6					0.09		0.3				5, 7, 9, 11c, 14, 17c
103	655/330	Heavy flint.....		(1) 42		3	3				52						0.6					6, 16
104	668/356	Chance, very dense barium flint.....	4675	(9) 36.6			4.9	0.2	13.6	4.7	39.2		0.2					0.2				11c, 13
105	680/317	Schott, heavy silicate flint.....	O192	(53) 33.0			5.0				56.8					0.04		0.2				10, 16, 17a
106	717/295	Chance, very dense flint.....	4141	(9) 35.1			2.8	0.1			61.8		0.1					0.2				13
107	717/295	Schott, heavy silicate flint.....	O41	(68) 33.7			4				62.0							0.3				5, 7, 11a, 16
108	751/276	Schott, heavy silicate flint.....	O500	(66) 29.3			3				67.5							0.2				2, 4, 14, 16, 17c
109	755/275	Schott, heavy silicate flint.....	O165	(68) 28.4			2.5				69							0.1				7, 9, 15
110	756/270	Extra dense flint.....		(1) 28			3				69											6, 16
111	778/265	Schott, very heavy silicate flint.....	O198	(68) 27.3			1.5				71							0.1				5, 7, 11c
112	890/226	Schott, very heavy silicate flint.....	S163	(68) 22.0							78.0											14, 15, 17c
113	905/217	Schott, heaviest silicate flint.....	S208	(66) 20							80											2, 11a
114	963/197	Schott, heaviest silicate flint.....	S57	(68) 18							82											7, 14, 15, 16
115		Kavalier combustion tube.....		(7) 79.57		0.66	11.60	7.80				0.11	0.32	0.04								
116		Experimental glass #7.....	165 <sup>III</sup>	(66) 73.8		10.5		7.0		5.0			3.5			0.2						2, 4
117		Experimental glass #34.....		(66) 70.2		12.0						3.0	4.5									2, 4
118		Experimental glass #90.....		(34) 69.5		2.0	16.0				2.5		2.5									2, 4
119		Experimental glass #87.....		(34) 68.2		10	9.5			2.0							0.4					4
120		Experimental glass #8.....	1419	(34) 67.9		16.8				5.8	8.1		1.0		0.1		0.2					2, 4
121		Experimental glass #84.....		(34) 67.7		8.0	10.0			9.0		5					0.3					4
122		Normal thermometer.....	16 <sup>III</sup>	(66) 67.3		2	14	7		7			2.5		0.2		0.3					2, 4, 7, 12c
122a		Same, analysis.....		(43) 66.58		0.91	14.80	Tr.	7.18	6.24		0.17	3.84	Tr.	0.28							
123		Jena combustion, analysis.....		(7) 66.90		7.22	2.40	7.94	7.27			0.61	6.38	0.22								
124		Experimental glass #3.....	172 <sup>III</sup>	(34) 64.4		8		8				11	4.5		0.1							2
125		Experimental glass #10.....	290	(66) 58.7									17				0.3					2, 4
126		Experimental glass #4.....	164 <sup>III</sup>	(34) 55.0		14																2
127		Experimental glass #32.....		(66) 54.8						17							0.2					2, 4
128		Experimental glass #12.....	121 <sup>III</sup>	(34) 51.3		14				5			4.5				0.2					2
129		Experimental glass #24.....		(66) 44.2			8										0.2					2, 4
130		Experimental glass #23.....		(66) 34.5		10.2							5				0.5					4
131				(6) 70.0			16.8			7.8			1.5				0.5					12b
132				(6) 67.9			16.8			4.5	6.6		1.0				0.3					12b
133			VS1419	(6) 69.64			17.0		5.0	5.8	8.1		1.0				0.4					12b
134	507/614	Schott, light borate crown.....	S205	(68) 69.64		69.1	8.0		4.7	5.3	2.6		18.0				0.2					2, 4, 7, 14, 15, 16
135	510/600	Schott, borate crown.....	S204	(68)		63.8	8.0	3.5			3.0		18.0				0.2					14, 17c
136	519/609	Schott, borate crown.....	VS458	(68)		64.0																
137	523/614	Schott.....	S185	(68)		71.8							30									7, 11b
138	573/469	Schott, borate flint.....	VS428	(68)		56.0							22.4									2
139	658/489	Schott, zinc borate.....	S665	(68)		41				59			12.0									7
140	666/392	Schott, borate flint.....	S120	(68)		42.8					52		5.0				0.2					2, 7, 14
141	516/703	Schott, light phosphate crown.....	O225	(68) 70.5		3.0																2, 7, 9, 15
142	522/697	Schott, light phosphate crown.....	S219	(66) 69.5		3.0							4.0				0.5					2
143	558/670	Schott, phosphate crown.....	S206	(66) 59.5		3.0							8.0				1.5					2, 4, 7, 15
144	562/646	Schott, medium phosphate crown.....	S179	(53) 57		3.0			28.0				1.5				1.5					14, 17c
145	562/665	Schott, phosphate crown.....	S40	(51) 59.5		3.0							5.0				1.5					15, 7
146	567/656	Schott, phosphate crown.....	S95	(66) 56.0		3.0			38				1.5				1.5					2

## MECHANICAL PROPERTIES OF GLASS

## Density

The density of glass is dependent not only on its composition but also on its thermal history; variation in the latter factor may cause differences of  $\pm 0.002$ . Figures 1-5 give the density-composition relations for a number of annealed experimental glasses. The density of four series of glasses of the general formula  $100 \text{ SiO}_2 \cdot 20$  or  $40 \text{ Na}_2\text{O}$  (or  $20$  or  $40 \text{ K}_2\text{O}$ )  $\cdot x\text{CaO}$  can be represented by the equation  $d = mx + b$ , in which  $x = \text{weight } \% \text{ CaO}$ . Values of  $m$ ,  $b$  and the range of  $x$  are: For  $20 \text{ Na}_2\text{O}$ :  $0.0124$ ,  $2.368$ ,  $3.7 - 23.7 \%$ ; for  $40 \text{ Na}_2\text{O}$ :  $0.0092$ ,  $2.475$ ,  $3.2 - 21 \%$ ; for  $20 \text{ K}_2\text{O}$ :  $0.0097$ ,  $2.386$ ,  $3 - 22 \%$ ; for  $40 \text{ K}_2\text{O}$ :  $0.0089$ ,  $2.464$ ,  $2.7 - 18.6 \%$  (45). The density of multicomponent commercial and experimental glasses is given in Table 2 and of optical glasses in Table 13.

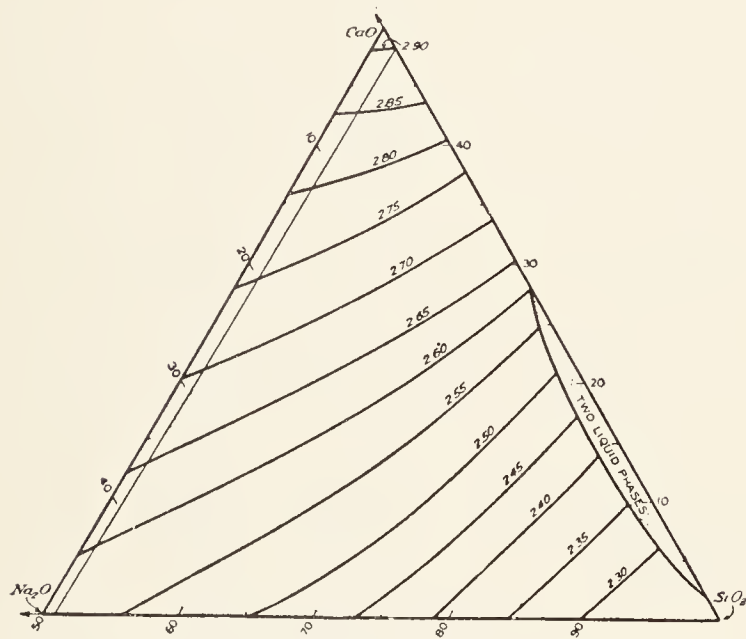


FIG. 1.—Density of the ternary  $\text{Na}_2\text{O}$ - $\text{CaO}$ - $\text{SiO}_2$  glasses. Composition in weight % (41).

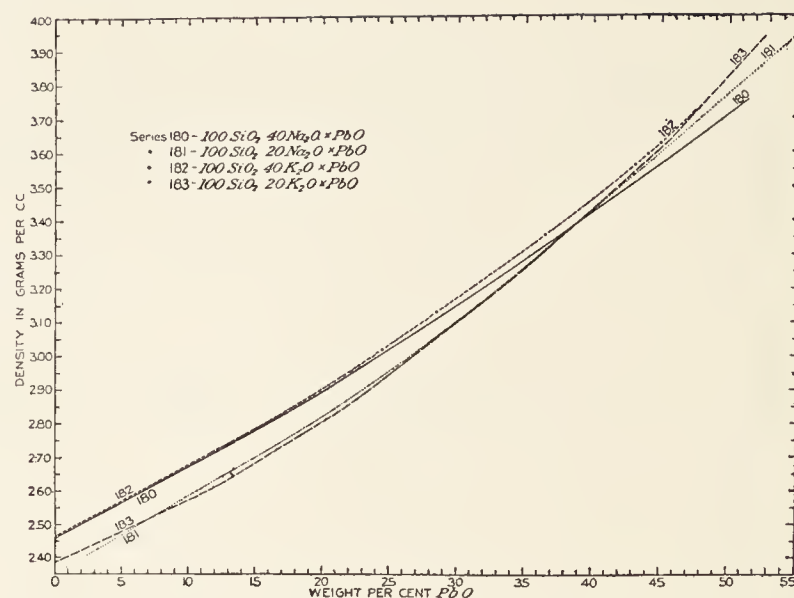


FIG. 3.—Density of some alkali-lead oxide glasses of the approximate composition shown (46).

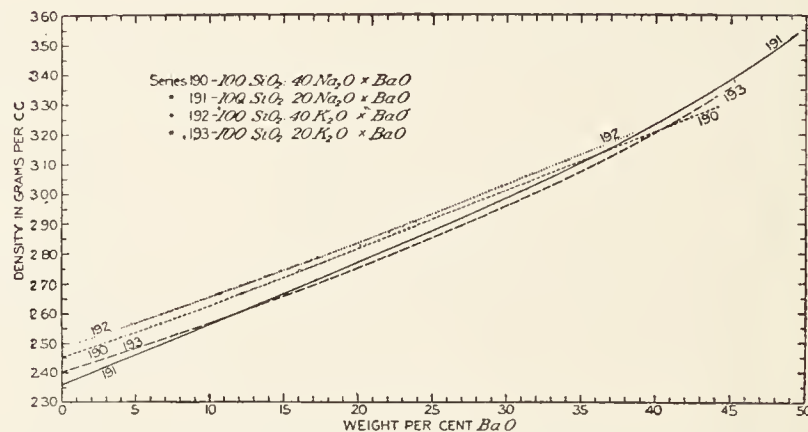


FIG. 4.—Density of some alkali-barium oxide glasses of the approximate composition shown (47).

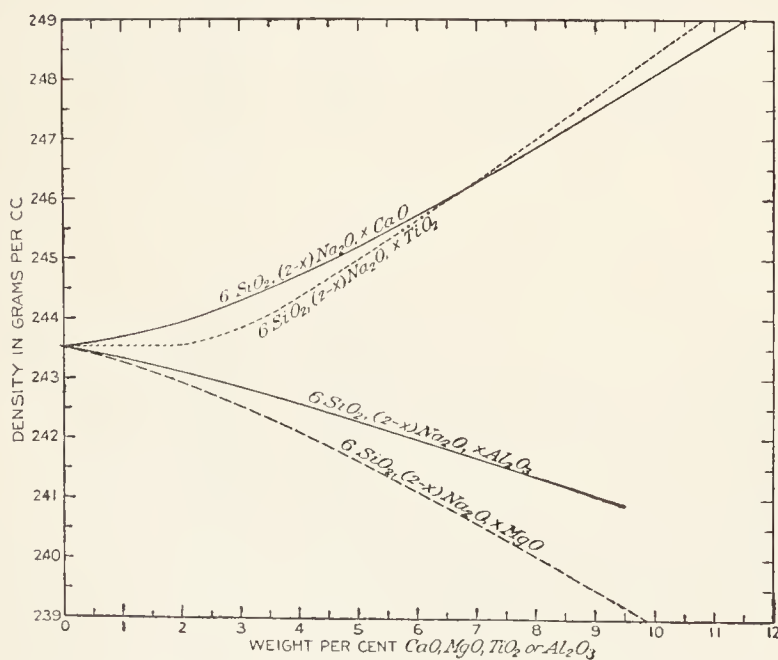


FIG. 2.—Density of some glasses obtained from  $\text{Na}_2\text{O} \cdot 3\text{SiO}_2$  by substitution of  $\text{CaO}$ ,  $\text{MgO}$ ,  $\text{Al}_2\text{O}_3$  or  $\text{TiO}_2$  for  $\text{Na}_2\text{O}$ . Exact compositions are given in the originals (19, 20, 24, 55).

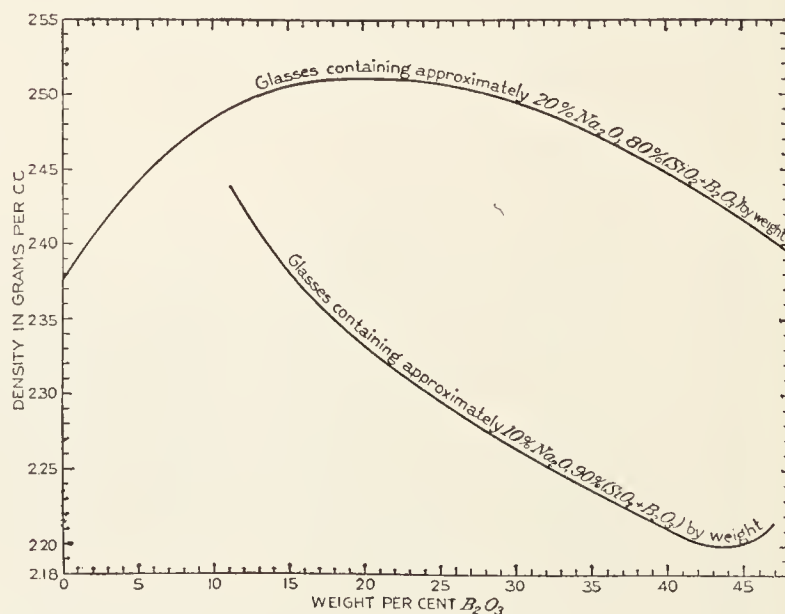


FIG. 5.—Density of some  $\text{Na}_2\text{O}$ - $\text{B}_2\text{O}_3$ - $\text{SiO}_2$  glasses. Exact compositions are given in the original (28).



TABLE 2.—PROPERTIES OF SOME MULTICOMPONENT GLASSES

Serial No.	Ind. No.	Type	Density g/cm <sup>3</sup>	Young's modulus	Poisson's ratio	Tensile strength	Compressive strength	Thermal expansion $\frac{10^6 \Delta l}{l \Delta t}$	Specific heat g-cal/g
				Unit = 1 kilo-megabarye; 1 megabarye = 14.50 lb./in. <sup>2</sup> = 1.020 kg/cm <sup>2</sup>					
1	1	Pyrex laboratory.....	2.25 (12)	611(12)				3.2 (19-350°)(12)	0.20(12)
1a	1a	Pyrex radio.....						3.0	
2	3	496/644.....	2.370(66)	715(65)	0.197(59)	0.68(66)	12.4(66)		0.204(65)
3	6	Thermometer, 59 <sup>III</sup> .....	2.370(66)	711(65)				5.90 (0-100)(34)	
4	7	506/602.....	2.5 (68)	644(65)	0.221(59)				
5	12	511/640.....	2.47 (68)	731(65)	0.210(59)				
6	14	513/637.....	2.47 (68)	781(65)	0.213(59)			7.97 (17.5-94.7)(51)	
7	15	513/573.....	2.572(66)	637(65)	0.226(59)	0.83(66)	9.6(66)		
8	21	516/536.....	2.6 (68)		0.219(59)				
9	22	517/609.....	2.49 (68)	704(65)				8.83 (18.7-90.5)(34)	
10	23	517/602.....	2.580(66)	647(65)	0.231(59)	0.66(66)	9.0(66)	9.63 (17-95.5)(51)	
11	60	571/430.....		598(65)	0.222(59)			7.93 (12.9-97.6)(51)	
12	62	573/580.....	3.21 (68)					7.90 (18.9-93.1)(51)	
13	63	573/576.....	3.21 (68)	727(65)	0.252(59)				
14	84	610/574.....	3.532(66)	783(65)	0.271(59)	0.73(66)	8.3(66)		0.140(65)
15	100	645/341.....	3.879(66)	535(65)	0.224(59)	0.53(66)	8.3(66)		
16	108	751/276.....	4.731(66)	537(65)	0.239(59)	0.52(66)	6.6(66)		
17	113	905/217.....	5.944(66)	499(65)	0.261(59)	0.35(66)	5.9(66)	9.33 (24.5-84)(51)	
18	116	165 <sup>III</sup> .....	2.479(66)	717(65)		0.82(66)	11.1(66)		0.196(65)
19	117		2.378(66)	704(65)		0.80(66)	9.7(66)		
20	118			621(65)	0.221(59)				
21	119			782(65)					
22	120		2.629(66)	651(65)		0.66(66)	9.7(66)		
23	122	Thermometer, 16 <sup>III</sup> .....	2.585(66)	732(65)	0.228(59)			8.03 (14.6-92.2)(34)	
24	124		2.424(66)						0.209(65)
25	125		2.518(66)	589(65)	0.253(59)	0.77(66)	6.7(66)		0.189(65)
26	126		2.480(66)						0.204(65)
27	127		2.668(66)	573(65)	0.261(59)	0.81(66)	7.2(66)		
28	128		2.848(66)	709(65)				4.57 (12.69-89.8)(34)	0.162(65)
29	129		3.578(66)	528(65)		0.60(66)	7.6(66)		
Borate glasses									
30	134	507/614.....	2.243(66)	461(65)	0.274(59)	0.57(66)	8.0(66)	6.71 (14.4-94.4)(51)	0.218(65)
31	137	523/614.....	2.238(66)		0.273(59)				0.232(65)
32	139	653/508.....	3.527(66)	801(65)	0.319(59)			3.33 (10.35-92.9)(51)	0.166(65)
33	140	666/392.....	3.691(66)						0.136(65)
Phosphate glasses									
34	141	516/700.....	2.588(66)					9.30 (17.7-92.7)(51)	0.190(65)
35	142	522/697.....	2.588(66)	664(65)	0.235(59)	0.55(66)	7.0(66)		
36	143	558/670.....	3.070(66)	620(65)	0.253(59)	0.75(66)	7.4(66)	8.70 (20.3-92.2)(51)	0.159(65)
37	146	567/656.....	3.238(66)		0.272(59)				0.146(65)

## Viscosity

For definition of viscosity see vol. 1, p. 42. The variation of viscosity with composition and with temperature in the ternary system  $\text{Na}_2\text{O}-\text{CaO}-\text{SiO}_2$  is shown in Figs. 6-12; the effect of replacement of  $\text{CaO}$  by  $\text{MgO}$  or by  $\text{Al}_2\text{O}_3$ , in Figs. 13 and 14 respt.; and the temperature-viscosity curves of a number of experimental glasses are shown in Fig. 15 and of optical glasses in Fig. 16.

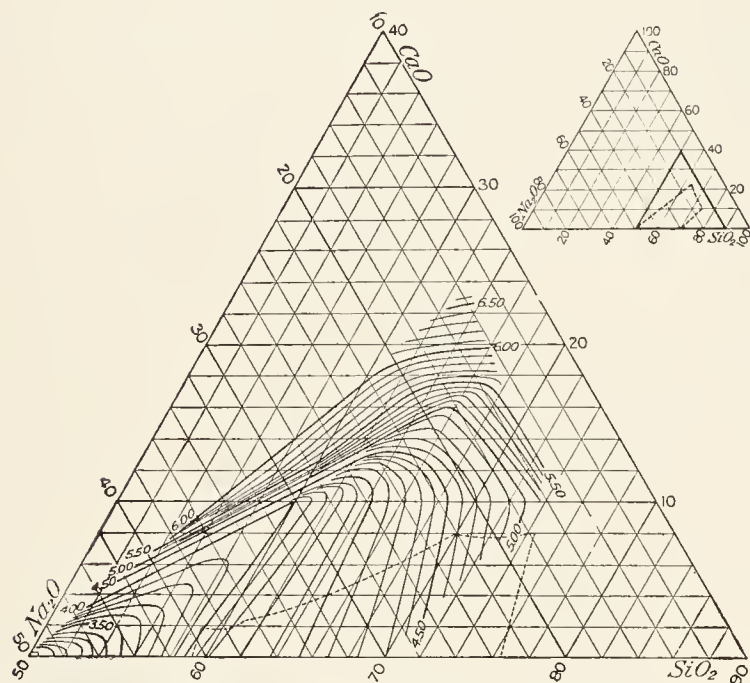


FIG. 6.—Log isokoms (lines of constant viscosity) in the system  $\text{Na}_2\text{O}-\text{CaO}-\text{SiO}_2$ , at  $900^\circ$ . Viscosity in log poises; composition in weight %. The broken line is the liquidus curve at  $900^\circ$ . Cf. Fig. 20 (61).

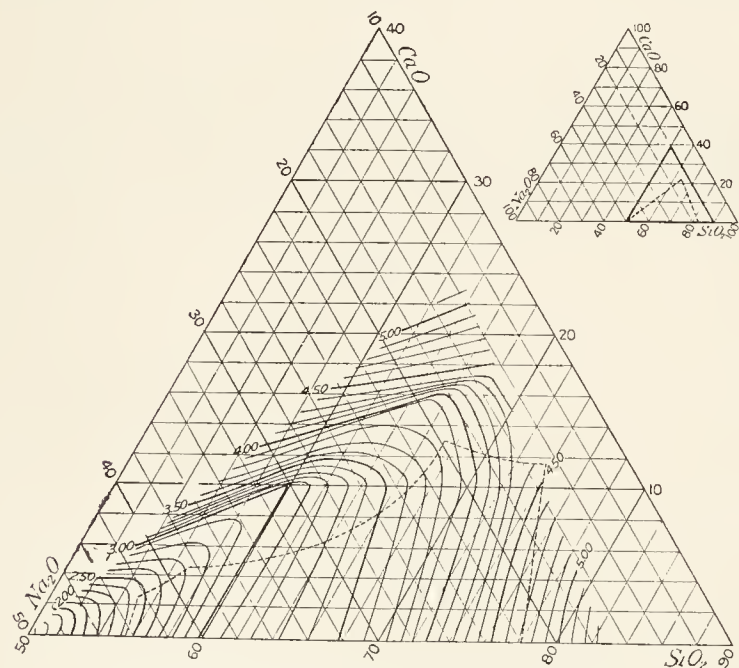


FIG. 7.—Log isokoms in the system  $\text{Na}_2\text{O}-\text{CaO}-\text{SiO}_2$  at  $1000^\circ$ . The broken line is the liquidus curve at  $1000^\circ$  (61).

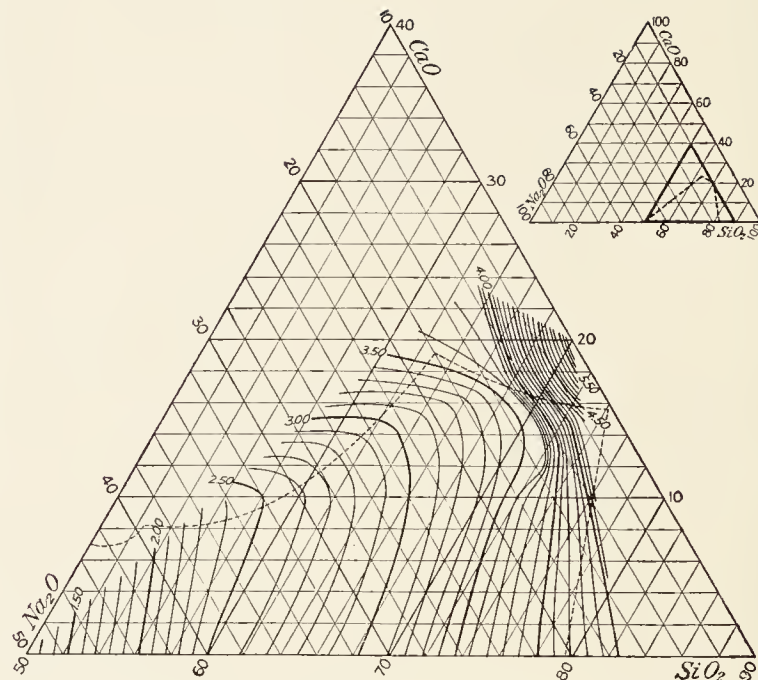


FIG. 8.—Log isokoms in the system  $\text{Na}_2\text{O}-\text{CaO}-\text{SiO}_2$  at  $1100^\circ$ . The broken line is the liquidus curve at  $1100^\circ$  (61).

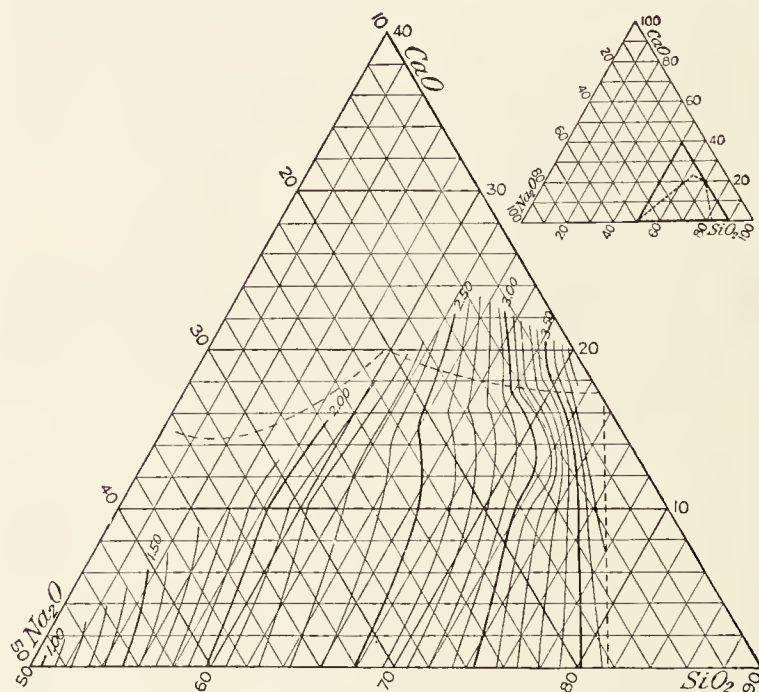


FIG. 9.—Log isokoms in the system  $\text{Na}_2\text{O}-\text{CaO}-\text{SiO}_2$  at  $1200^\circ$ . The broken line is the liquidus curve at  $1200^\circ$  (61).



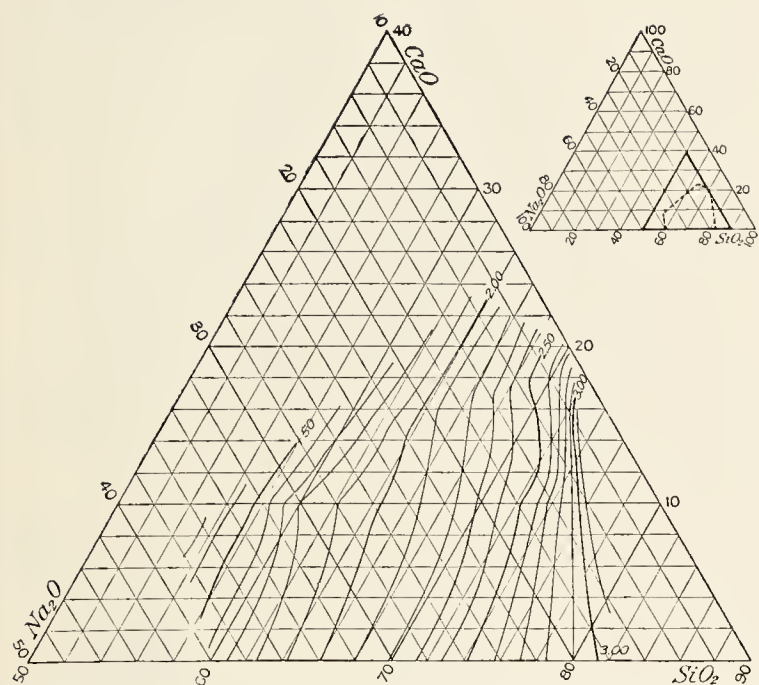


FIG. 10.—Log isokoms in the system  $\text{Na}_2\text{O}-\text{CaO}-\text{SiO}_2$  at  $1300^\circ$ . The mixtures at this temperature are all above the liquidus surface, except a few high in  $\text{SiO}_2$  (<sup>61</sup>).

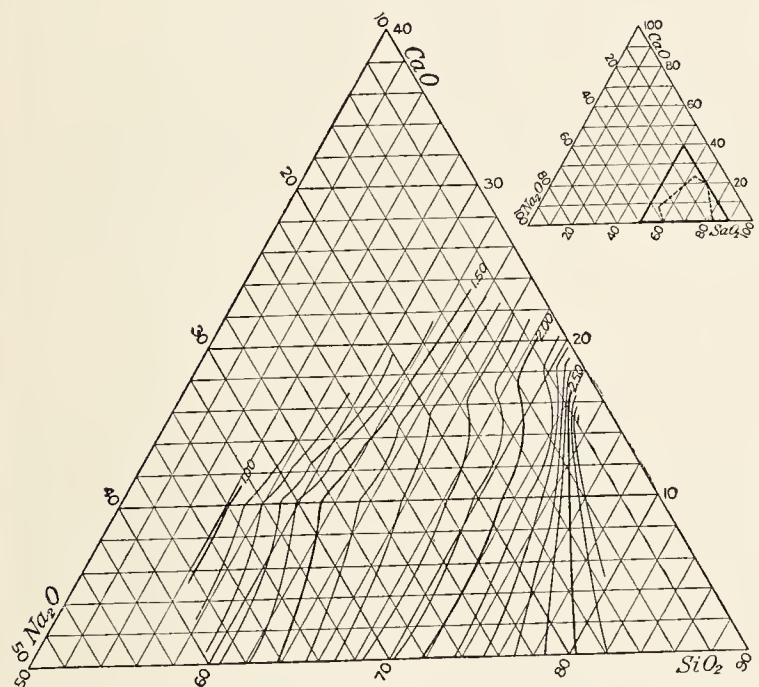


FIG. 11.—Log isokoms in the system  $\text{Na}_2\text{O}-\text{CaO}-\text{SiO}_2$  at  $1400^\circ$  (<sup>61</sup>).

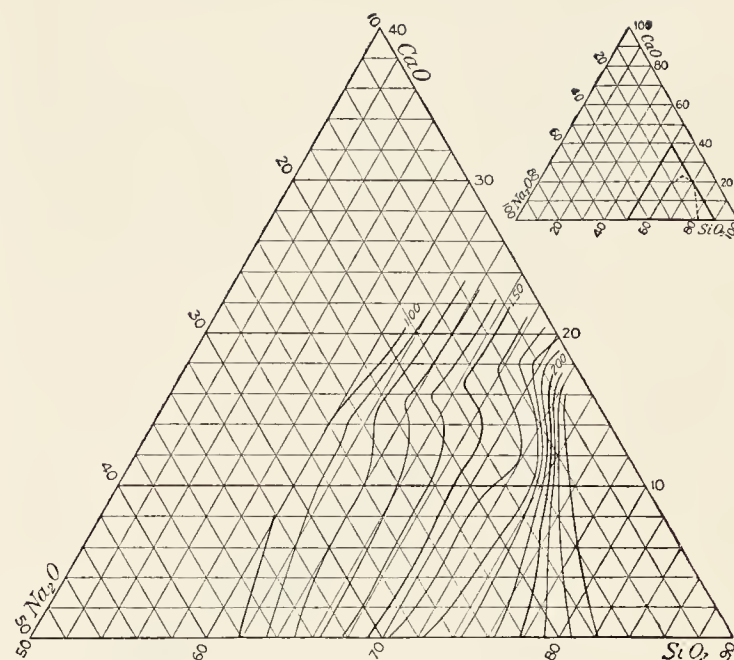


FIG. 12.—Log isokoms in the system  $\text{Na}_2\text{O}-\text{CaO}-\text{SiO}_2$  at  $1500^\circ$  (<sup>61</sup>).

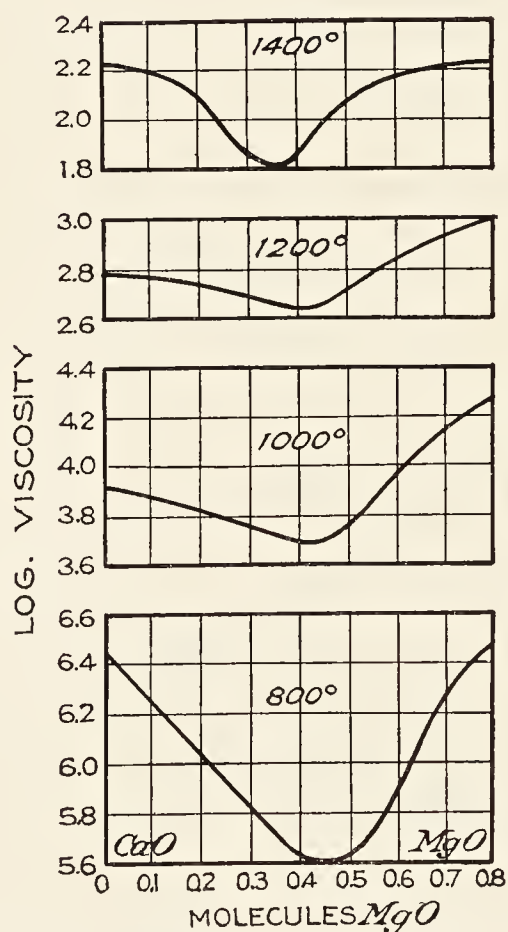


FIG. 13.—Effect on viscosity of replacing  $\text{CaO}$  by  $\text{MgO}$  in the mixture  $1.2\text{Na}_2\text{O} \cdot 0.8\text{CaO} \cdot 6\text{SiO}_2$ , at different temperatures. Viscosity in poises (<sup>14.1</sup>).

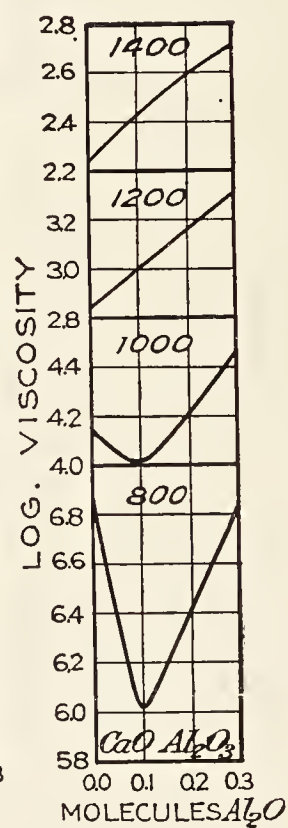


FIG. 14.—Effect on viscosity of replacing  $\text{CaO}$  by  $\text{Al}_2\text{O}_3$  in the mixture  $1.1\text{Na}_2\text{O} \cdot 0.9\text{CaO} \cdot 6\text{SiO}_2$ , at different temperatures (<sup>14.1</sup>).

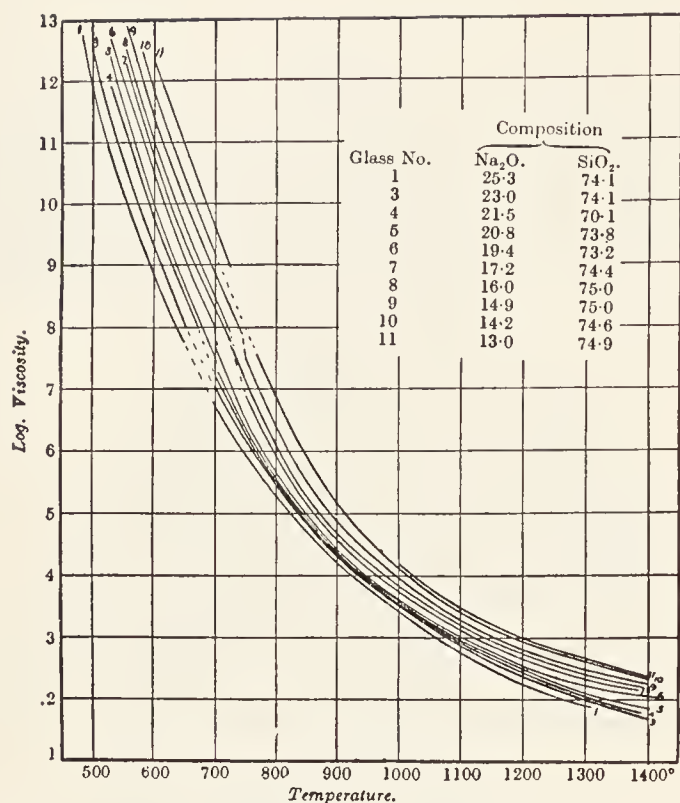


FIG. 15.—Variation of log viscosity, in poises, with temperature, of a number of experimental glasses (<sup>14</sup>).

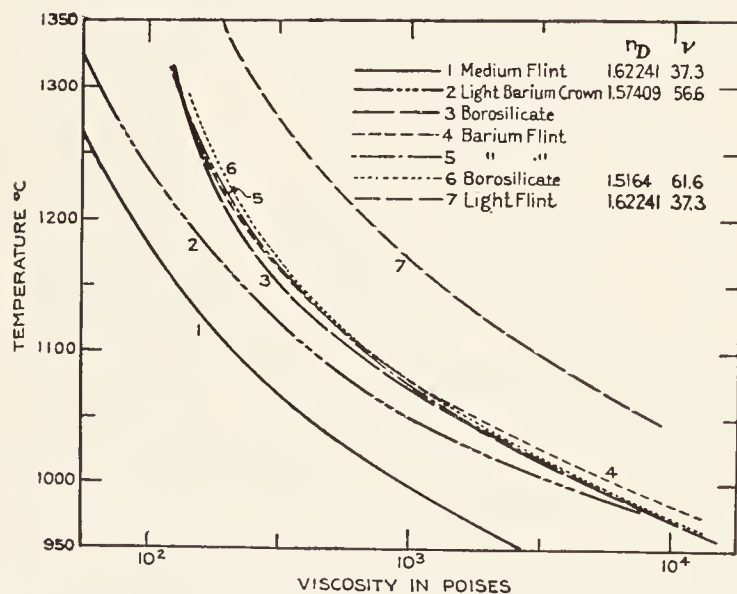


FIG. 16.—Variation of viscosity with temperature in a number of optical glasses (<sup>61.1</sup>).

### Surface Tension

The variation of surface tension with composition in the ternary Na<sub>2</sub>O-CaO-SiO<sub>2</sub> glasses at constant temperature is shown in Figs. 17 and 18; the variation with temperature in Fig. 19.

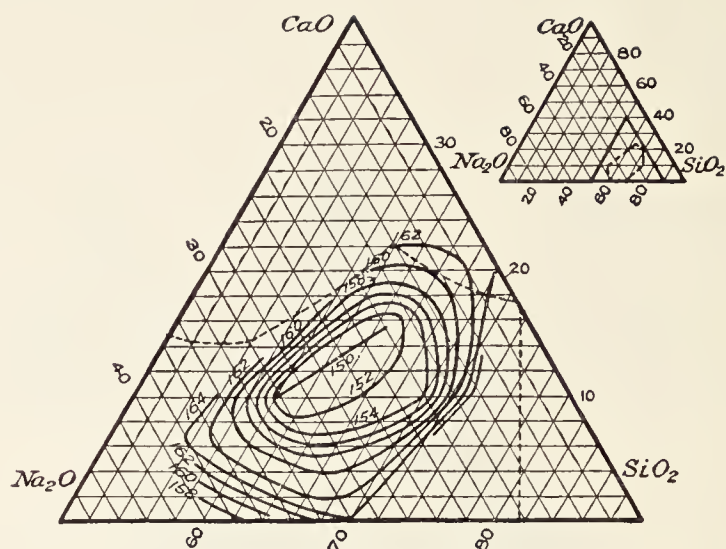


FIG. 17.—Surface tension of Na<sub>2</sub>O-CaO-SiO<sub>2</sub> mixtures at 1206° (<sup>61</sup>).

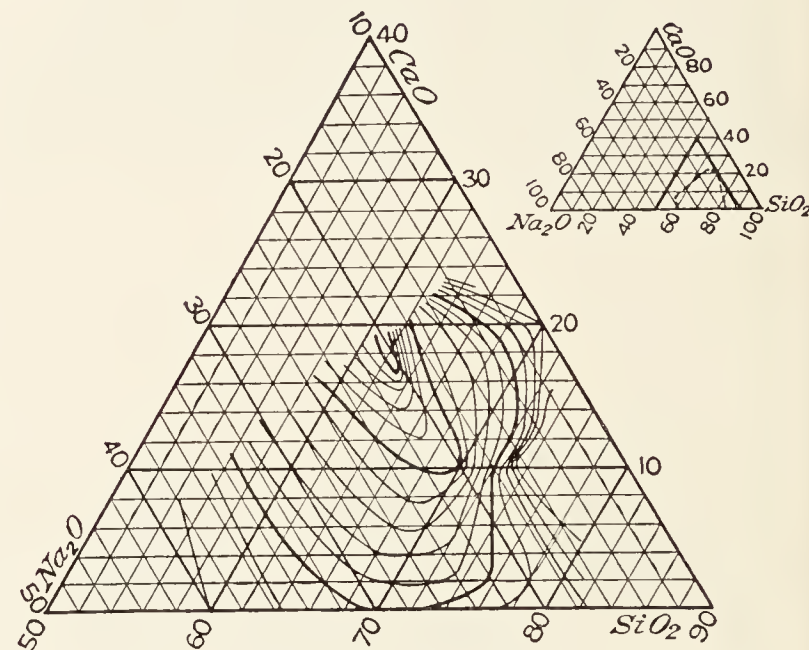


FIG. 18.—Surface tension of Na<sub>2</sub>O-CaO-SiO<sub>2</sub> mixtures at 1454° (<sup>61</sup>).

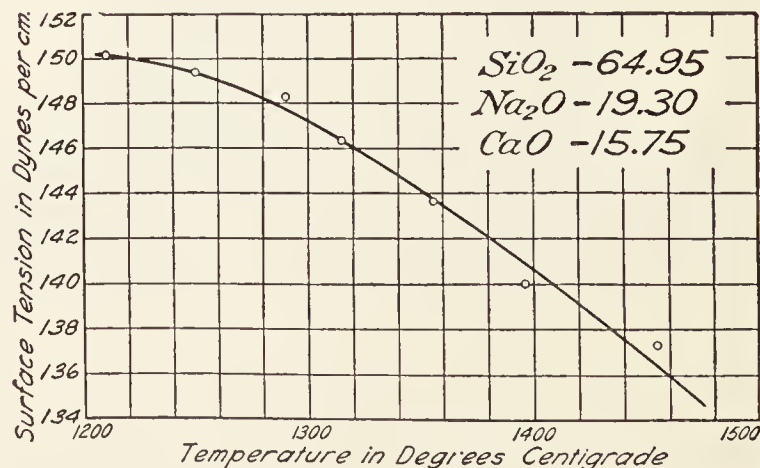


FIG. 19.—Variation of surface tension with temperature (<sup>61</sup>).



## Strength

The strength of glass is so greatly influenced by its thermal history (33) and the condition of its surface (38) that the values given are of uncertain significance and should be used only with an ample factor of safety.

Values of tensile and compressive strength of a number of glasses are given in Table 2. The strength of glass fibers as a function of thickness is given by Griffith (33). The following summarizes the data for tubes, determined on a glass of unknown composition.

TABLE 3.—BURSTING STRENGTH OF GLASS TUBES (44)

Maximum fiber stress,  $T_m$ , calculated from the formula

$$T_m = \frac{1}{4} \left[ 5P_m + 7 \left( \frac{P_m - 1}{\left( \frac{R}{R'} \right)^2 - 1} \right) - 1 \right] \text{ (unit = } 10^6 \text{ barye)}$$

Shape of tubes	Range of radii, $R$ , mm		Number tubes tested	Range of bursting pressures, $P_m$	Max. fiber stress, $T_m$	Mean var. from mean, %
	External, $R$	Internal, $R'$				
Thick walled..	9-18	3-6	9	230-380	470	14
Capillary.....	5-7	0.24-1.0	16	420-1200	902	27
Thin walled..	3.8-7.8	3.4-7.3	17	54-377	628	20

## Elastic Properties

Young's modulus,  $E$ , and Poisson's ratio,  $\sigma$ , for a number of commercial and experimental glasses are given in Table 2; the rigidity and bulk moduli,  $C$  and  $K$ , are related to these through the equation  $C = E/2(1 + \sigma)$  and  $K = E/3(1 - 2\sigma)$ . The variation of  $E$ , in kilo-megabaryes, with weight % of CaO is given by the equation  $E = 13.9y + 565.6$ , in the range 0-11% CaO (10a). The variation of Young's modulus with temperature is shown in Table 4.

TABLE 4.—THE EFFECT OF TEMPERATURE ON ELASTICITY (66)

$E_t = E_{20} [1 - \alpha(t - 20)^\beta]$ ; range, room temp. to  $t_{\max}$ . (unit:  $10^9$  barye)

Ind. No.	Glass Type	$E_{20}^\circ$	$\log_{10}\alpha$	$\log_{10}\beta$	$t_{\max}$
3	496/644	752	9.018	0.428	482
7	506/602	655	4.618	0	448
12	511/640	740	4.352	0	475
15	513/573	684	5.912	0.065	409
22	517/609	709	4.369	0	433
23	517/602	654	4.575	0	394
45	545/503	549	15.452	0.706	383
60	571/430	609	10.973	0.499	374
63	573/575	744	6.923	0.165	427
100	645/341	540	24.492	0.945	340
108	751/276	539	8.634	0.401	357
116		738	5.543	0.082	460
117		721	5.114	0	482
118			4.616	0	434
119		817	4.248	0	447
120		652	15.401	0.717	433
121		741	11.092	0.553	407
122		730	6.435	0.232	426
125		604	5.696	0.113	455
127		577	4.193	0	417
129		532	13.897	0.643	413
130		798	5.330	0.094	486
134	507/614	492	4.449	0	281
143	558/670	631	6.230	0.255	412

## THERMAL PROPERTIES OF GLASS

## Melting Point Diagrams

The melting point diagrams showing the compositions of the crystalline solid phases which may exist in equilibrium with liquid and the relation between equilibrium temperature and composition of that liquid are not known for most of the glass-forming systems. Figures 20 and 21 give these for the ternary system  $\text{Na}_2\text{O} \cdot \text{SiO}_2$ - $\text{CaO} \cdot \text{SiO}_2$ - $\text{SiO}_2$  and the binary system  $\text{PbO}$ - $\text{SiO}_2$ .

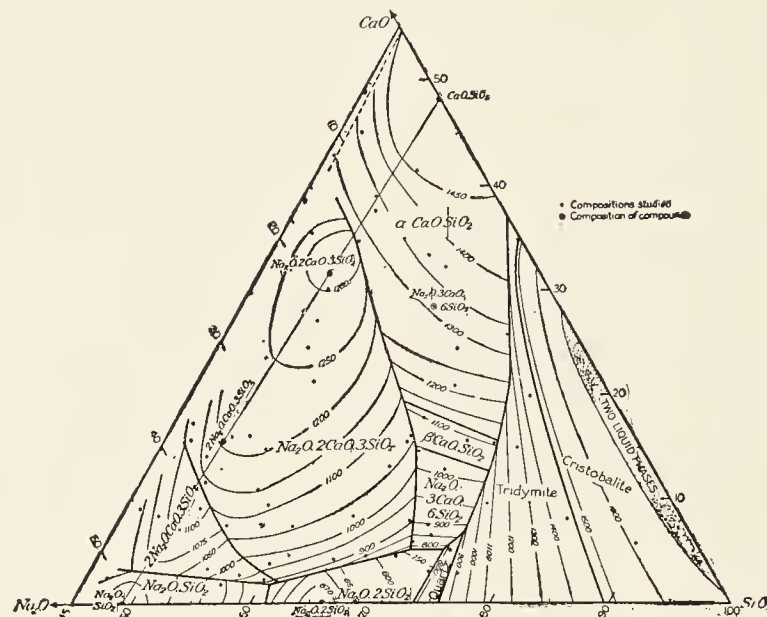
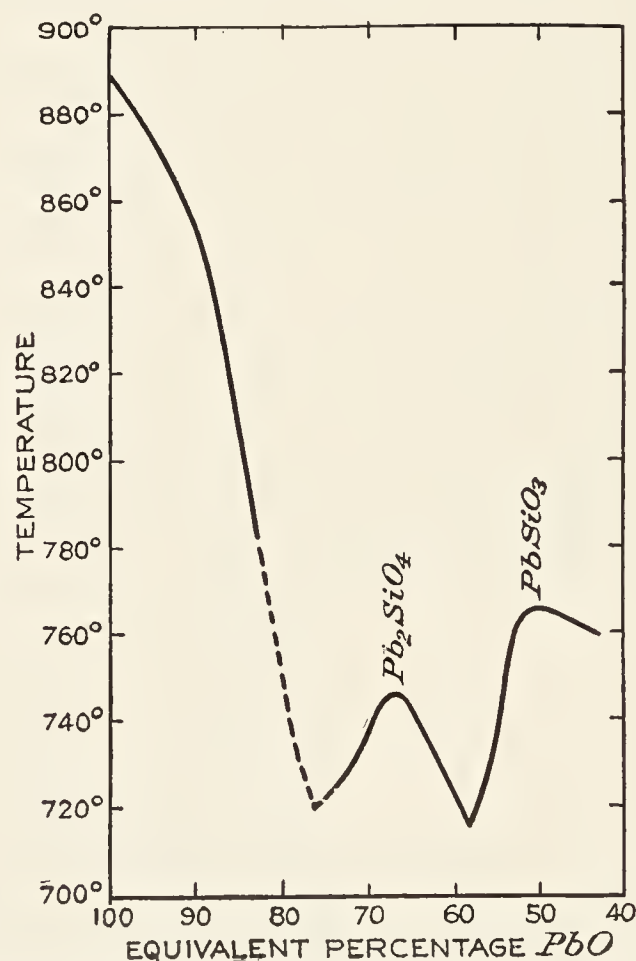
FIG. 20.—Melting point diagram of the system  $\text{Na}_2\text{O}$ - $\text{CaO}$ - $\text{SiO}_2$ . Composition in weight % (39).FIG. 21.—Melting point diagram of the system  $\text{PbO}$ - $\text{SiO}_2$  (11).

TABLE 5.—THERMAL CONSTANTS OF REPRESENTATIVE GLASSES

Glasses are undercooled liquids, and hence have no melting points. Following are some of the empirical definitions that have been proposed for characterizing glasses as to their thermal behavior, and the corresponding temperatures for some representative glasses. (a) Annealing temperature (<sup>62</sup>): the temperature at which the ratio of final to initial strain is a minimum, when heating and cooling are carried out in a prescribed manner; *v. also* Table 6 and Figs. 22, 23 and 24. (b) Deformation temperature (<sup>62</sup>): the lowest temperature at which, after 6 hr, one observes a deformation of the polished faces of a 20 mm cube embedded in kieselguhr with a diagonal vertical. (c) Cohesion temperature (<sup>69</sup>): the lowest temperature at which 2 plane polished pieces, 2 mm thick, 10 mm diameter, will coalesce in 30 min. (d) Softening temperature, for pyrex (<sup>12</sup>): the temperature at which a rod 9 in. long and 0.6 mm diameter lengthens under its own weight at the rate of 1 mm per min when heated in an electric furnace throughout its upper 9.5 cm of length. For the rest of the glasses (<sup>69</sup>), the constant  $t_0$  in the empirical 3-constant equation  $(t_0 - t)(S + S_0) = C$ , expressing the relation between the stress,  $S$  (measured by birefringence), produced by quickly cooling a cm cube from the temperature  $t$ . (e) Flow temperature (<sup>63</sup>): the temperature at which a 25 mm cube embedded in kieselguhr with diagonal vertical flows until the corner cannot be detected, in the given time.

TABLE 5.—CONSTANTES THERMIQUES DES VERRES REPRÉSENTATIFS

Les verres sont des liquides surfondus, et par conséquent ne possèdent pas de point de fusion. Dans ce qui suit, on trouvera quelques-unes des définitions empiriques qui ont été proposées pour caractériser les verres en se basant sur la façon dont ils se comportent au point de vue thermique, et les températures correspondantes pour quelques verres représentatifs. (a) Température de recuit (<sup>62</sup>): c'est la température à laquelle le rapport de la tension finale à la tension initiale devient minimum, lorsque la conduite du chauffage et du refroidissement est effectuée d'une manière prescrite; voir aussi Table 6. (b) Température de déformation (<sup>62</sup>): c'est la température la plus basse à laquelle on observe, après six heures, une déformation des faces polies d'un cube de 20 mm de côté, disposé dans du kieselguhr avec une diagonale verticale. (c) Température de cohésion (<sup>69</sup>): c'est la température la plus basse à laquelle deux pièces polies planes de 2 mm d'épaisseur et de 10 mm de diamètre s'accrocheront en trente minutes. (d) Température de ramollissement; pour le Pyrex (<sup>12</sup>): c'est la température à laquelle une baguette de 23 cm de long. et de 0,6 mm de diamètre s'allonge sous son propre poids à raison de 1 mm par min, la baguette étant chauffée dans un four électrique sur une longueur de 9,5 cm. Pour le reste des verres (<sup>69</sup>), la constante  $t_0$  dans l'équation empirique à 3 constantes  $(t_0 - t)(S + S_0) = C$ , exprimant la relation entre la tension,  $S$  (mesurée par biréfringence), produite par un refroidissement rapide d'un cube de 1 cm de côté de la température  $t$ . (e) Température d'écoulement (<sup>63</sup>): c'est la température à laquelle un cube de 25 mm de côté, disposé dans du kieselguhr, avec une diagonale verticale, s'écoule d'une façon telle que le coin ne peut plus être décelé dans un temps donné.

TAFEL 5.—THERMISCHE KONSTANTEN TYPISCHER GLASSORTEN

Gläser sind unterkühlte Flüssigkeiten und haben deshalb keinen Schmelzpunkt. Im folgenden sind einige empirische Definitionen angegeben, welche zur Charakterisierung des thermischen Verhaltens von Gläsern herangezogen werden. Auf die entsprechende Temperatur so bezogen, ist das thermische Verhalten einiger typischer Glassorten ebenfalls angegeben. (a) Kühltemperatur (<sup>62</sup>): Die Temperatur bei welcher das Verhältnis der Endspannung zur Anfangsspannung ein Minimum ist, wenn Erwärmung und Kühlung in vorgeschriebener Weise erfolgt. Siehe Tafel 6 und Fig. 22, 23 und 24. (b) Deformations-Temperatur (<sup>62</sup>): Die tiefste Temperatur bei welcher nach 6 Stunden eine Deformation der polierten Flächen eines 20 mm Würfels bemerkt wird, welcher in Kieselgur eingebettet ist (mit vertikaler Diagonale). (c) Kohäsions-Temperatur (<sup>69</sup>): Die tiefste Temperatur bei welcher zwei plan geschliffene Flächen, 2 mm dick, 10 mm Durchmesser in 30 Minuten zusammenschmelzen. (d) Erweichungs-Temperatur für Pyrex-Glas (<sup>12</sup>): Die Temperatur bei welcher ein Stab von 23 cm Länge und 0,6 mm Durchmesser, bei der Erhitzung der ersten oberen 9,5 cm seiner Länge, im elektrischen Ofen, unter dem eigenen Gewicht eine minutliche Verlängerung um 1 mm erfährt. Für den Rest der Gläser (<sup>69</sup>) ist  $t_0$  die Konstante der empirischen Gleichung (drei Konstanten)  $(t_0 - t)(S + S_0) = C$ , welche die Beziehung zum Druck  $S$  herstellt, der durch eine rasche Kühlung von der Temperatur  $t$  herunter in einem 1 cm Würfel erzeugt wird (Druckmessung nach der Doppelbrechung). (e) Fluss-Temperatur (<sup>63</sup>). Ist die Temperatur bei welcher ein 25 mm Würfel in Kieselgur eingebettet (diagonal, vertikal) zerfließt, so, dass in der gegebenen Zeit die Ecken nicht mehr erkannt werden können.

TABELLA 5.—COSTANTI TERMICHE DI VETRI TIPICI

I vetri sono liquidi sopra-raffreddati e non hanno pereio punto di fusione.

Qui sono indicate alcune delle proprietà proposte per caratterizzare i vetri dal punto di vista del loro comportamento termico, e sono riportate le temperature corrispondenti per alcuni vetri tipici. (a) Temperatura di (ricottura) (<sup>62</sup>): la temperatura alla quale è minimo il rapporto fra tensione finale e iniziale, quando riscaldamento e raffreddamento vengono eseguiti in una maniera prescritta. Vedi pure Tabella 6, e Fig. 22, 23 e 24. (b) Temperatura di deformazione (<sup>62</sup>): la temperatura più bassa alla quale, dopo sei ore, si osserva deformazione delle facce pulimentate di un cubo di 20 mm immerso nella farina fossile con una diagonale in posizione verticale. (c) Temperatura di adesione (<sup>69</sup>): la temperatura più bassa alla quale aderiscono in 30 minuti due pezzi pulimentati a superficie piana di 2 mm di spessore e 10 di diametro. (d) Temperatura di rammolimento. Per il Pyrex (<sup>12</sup>) è la temperatura alla quale una bacchetta di 23 cm di lunghezza e 0,6 mm di diametro si distende sotto il proprio peso alla velocità di 1 mm per minuto quando sia scaldata in un forno elettrico lungo i 9,5 cm superiori di lunghezza; per gli altri vetri (<sup>69</sup>) è la costante  $t_0$  nella equazione empirica a 3 costanti  $(t_0 - t)(S + S_0) = C$ , esprime la relazione tra sforzo,  $S$  (misurato dalla birifrangenza), prodotto raffreddando rapidamente un cubo di un centimetro dalla temperatura  $t$ . (e) Temperatura di scorrimento (<sup>63</sup>): la temperatura alla quale un cubo di 25 mm immerso in farina fossile con una diagonale disposta verticalmente, scorre fino a non potersi più distinguere il vertice nel tempo indicato.



Ind. No.	Annealing (a)	Deformation (b)	Co-hesion (c)	Softening (d)	Flow temperatures (e)		
					30 min	2 hr	6 hr
1				815(12)			
3				648(69)			
12		570(62)	603(69)				
17	495(62)	605(62)	583(69)	565(69)	850(63)	815(63)	755(63)
24			555	647	810(63)	795(63)	780(63)
47			505	498(40)	740	725	685
57			632	640			
63			632	639	910	885	860
70			484	499			
71		590	632	642	845	805	785
80	585	645	694	681	845	830	795
87		650	694	735	870	835	820
90	565	645	686	681	840	815	800
91	410	460	486	490	730	695	680
98		585	547	595	780	730	685
100	390	430	493	491	660	645	630
107			465	473			
111			457	469			

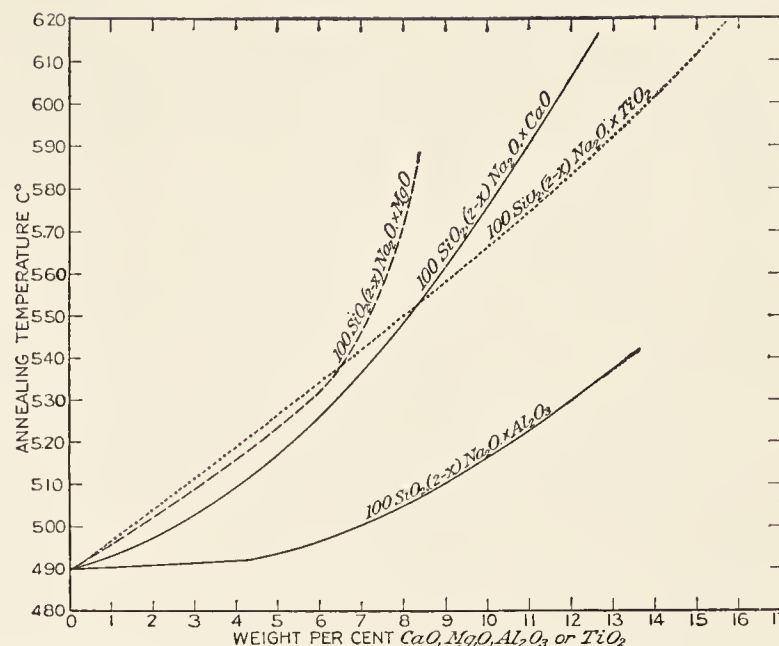


FIG. 23.—Annealing temperatures of glasses derived from  $\text{Na}_2\text{O} \cdot 3\text{SiO}_2$ , by substitution of  $\text{CaO}$ ,  $\text{MgO}$ ,  $\text{Al}_2\text{O}_3$  or  $\text{TiO}_2$  for  $\text{Na}_2\text{O}$ . Exact compositions are given in the original (15, 17, 21, 55).

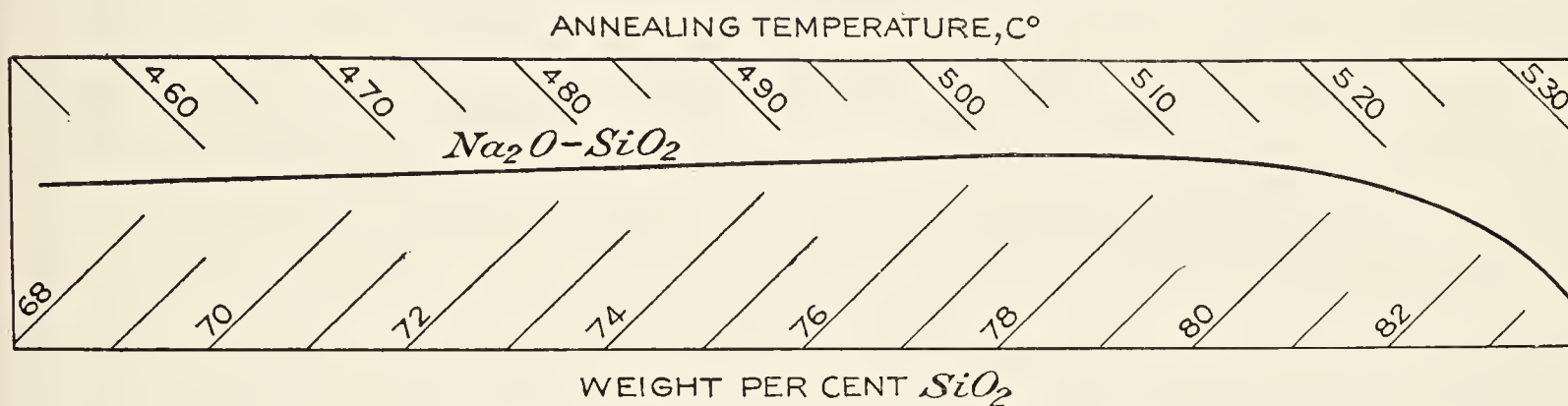


FIG. 22.—Annealing temperature of  $\text{Na}_2\text{O}-\text{SiO}_2$  glasses (14).

#### Annealing Temperature

Figures 22, 23 and 24 show the relation between annealing temperature and composition of a number of experimental glasses; in these, the annealing temperature is that at which strain disappears rapidly. Table 6 gives the annealing constants of a number of optical glasses.

TABLE 6.—ANNEALING TEMPERATURES

Values of  $M_1$  and  $M_2$  in equation  $\log_{10} A = M_1\theta - M_2$ , in which  $\theta = \text{temp., } ^\circ\text{C}$ , and  $M_1$  and  $M_2$  are experimental constants, from which may be calculated the annealing constant  $A$ . The annealing temperature is defined as that temperature at which the strain will decrease from 50 to  $2.5\mu\mu$  in 2 min, calculated from the formula  $At = 1/\Delta n - 1/\Delta n_0$  in which  $t = \text{time in min}$ ,  $\Delta n = \text{birefringence in } \mu\mu$ .

Ind. No.	Type	$M_1$	$M_2$	Annealing temp., $^\circ\text{C}$
19	516/620	0.030	18.68	599
36	523/590	0.029	17.35	573
65	573/420	0.033	15.92	461
67	574/570	0.032	20.10	606
82	606/440	0.028	16.28	556
83	608/570	0.038	24.95	638
95	616/370	0.038	18.34	464
103	655/330	0.037	17.51	454
110	756/270	0.033	15.03	434

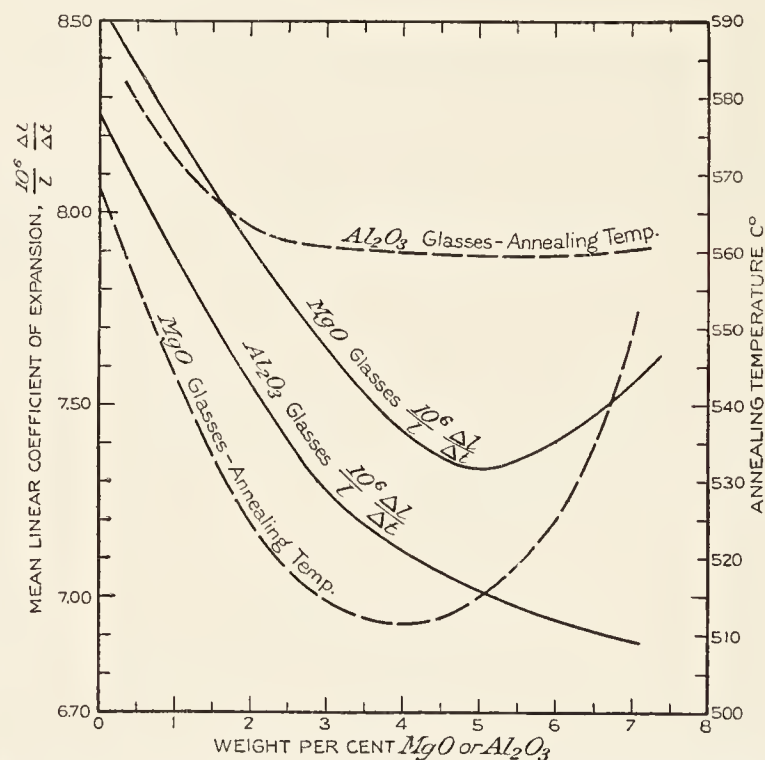


FIG. 24.—Annealing temperatures and thermal expansions of glasses derived from  $1.2\text{Na}_2\text{O} \cdot 0.8\text{CaO} \cdot 6\text{SiO}_2$  by substitution of  $\text{CaO}$  by  $\text{MgO}$ ; and from  $1.1\text{Na}_2\text{O} \cdot 0.9\text{CaO} \cdot 6\text{SiO}_2$  by substitution of  $\text{CaO}$  by  $\text{Al}_2\text{O}_3$  (21, 25).

## Coefficient of Expansion

The linear coefficient of expansion,  $\alpha = 10^6 \Delta l / l \Delta t$ , of multicomponent commercial and experimental glasses is given in Tables 2 and 7 and for a systematic series of experimental glasses in Figs. 24-28.

TABLE 7.—COEFFICIENT OF THERMAL EXPANSION  
(V. also Table 2)  $l = l_0 (1 + 10^{-6} \alpha t)$

Ind. No.	$\alpha$	Range, °C	Lit.	Ind. No.	$\alpha$	Range, °C	Lit.
13	9.12	18-97	(34)	71	7.02		(69)
17	7.79		(69)	74	8.8	22-451	(48)
23	9.20	37 (mean)	(34)	34.7	494-512	(48)	
	10.04	93 (mean)	(34)	75	8.23		(69)
	10.61	151 (mean)	(34)	78	7.0	23-420	(48)
	11.11	212 (mean)	(34)		2.92	495-511	(48)
24	9.00		(69)	80	5.87		(69)
26	10.2	22-426	(48)	87	6.48		(69)
	55.5	502-522	(48)	91	7.88	11-99	(51)
28	10.4	24-422	(48)	98	8.76		(69)
	54.8	494-507	(48)	102	8.75		(69)
30	9.00	22-498	(48)	107	8.33		(69)
	39.3	539-562	(48)	109	8.03	20-94	(34)
33	9.03	16-94	(34)	111	8.18		(69)
45	5.23	7-92	(34)	114	9.34	18-99	(51)
47	8.14		(69)	134	6.74	14-94	(34)
51	8.8	22-494	(48)	136	5.60	0-100	(34)
	33.1	519-550	(48)	138	5.37	0-100	(34)
54	7.74		(69)	141	9.30	18-93	(34)
61	9.00	10-93	(34)	145	8.71	21-100	(51)
64	9.0	23-499	(48)	122	*	-253 to +100	(2)
	64.9	569-610	(48)				

\*  $l = l_0 \{ 1 + 10^6 [716.8 (T/100) + 48.33 (T/100)^2 + 9.02 (T/100)^3 + 10.9 (T/100)^4] \}$ .

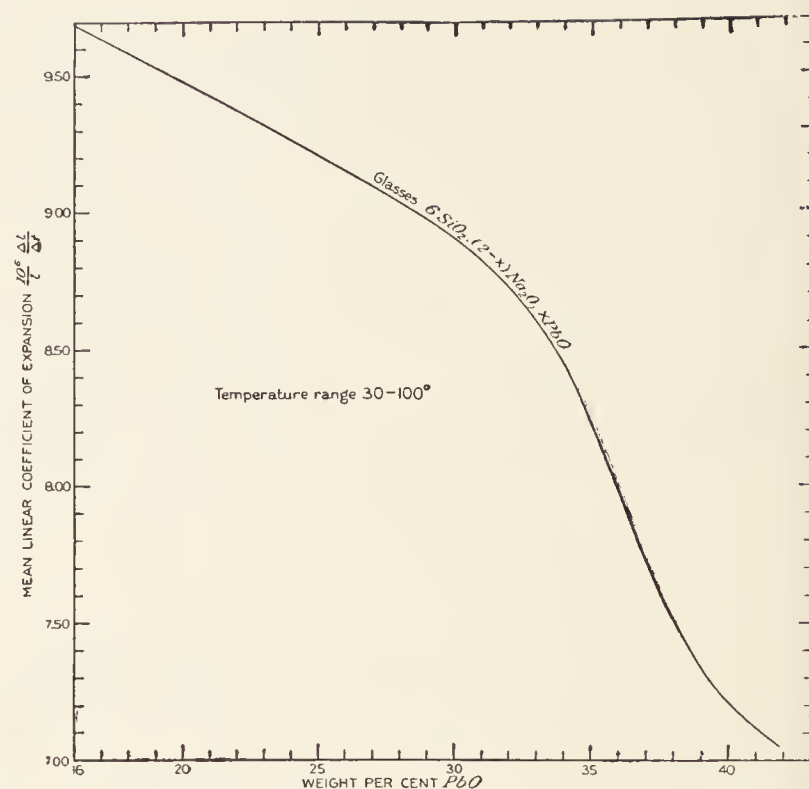


FIG. 27.—Thermal expansion of glasses derived from  $\text{Na}_2\text{O} \cdot 3\text{SiO}_2$  by substitution of  $\text{PbO}$  for  $\text{Na}_2\text{O}$  (42).

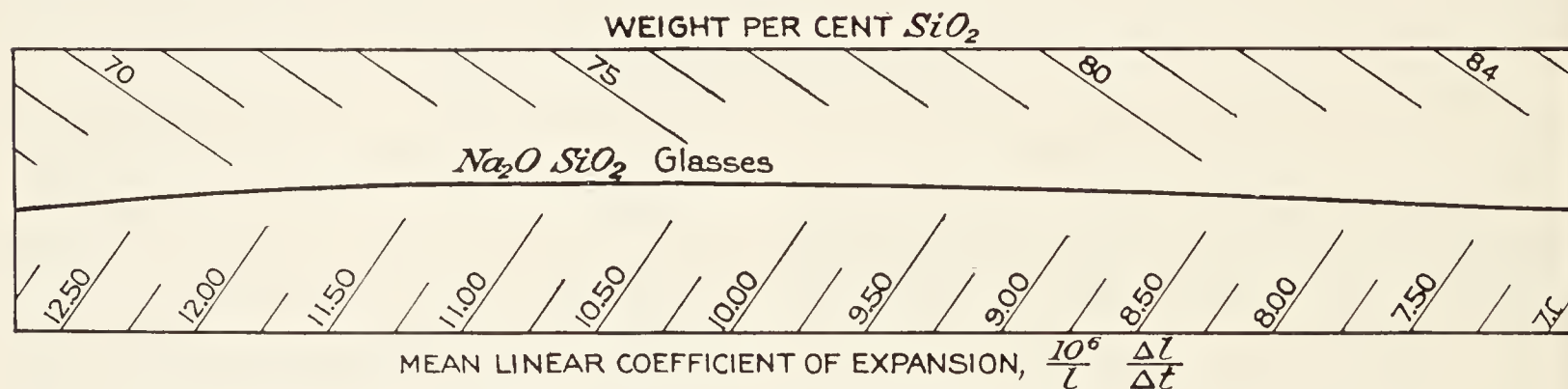


FIG. 25.—Thermal expansion of  $\text{Na}_2\text{O}-\text{SiO}_2$  glasses (22).

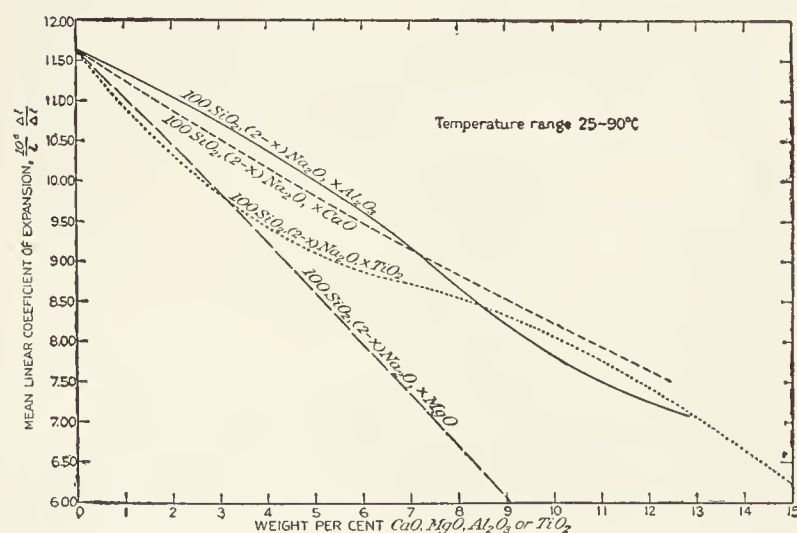


FIG. 26.—Thermal expansion of glasses derived from  $\text{Na}_2\text{O} \cdot 3\text{SiO}_2$  by substitution of  $\text{CaO}$ ,  $\text{MgO}$ ,  $\text{Al}_2\text{O}_3$  or  $\text{TiO}_2$  for  $\text{Na}_2\text{O}$ . Exact compositions are given in the original (16, 18, 23, 55).

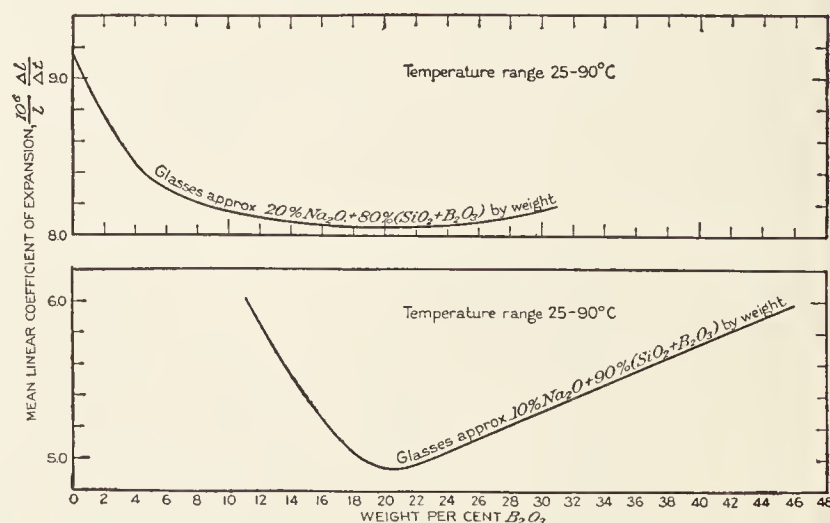


FIG. 28.—Thermal expansion of  $\text{Na}_2\text{O}-\text{B}_2\text{O}_3-\text{SiO}_2$  glasses (28)



## SPECIFIC HEAT

The specific heats of commercial and experimental glasses are given in Table 2; Table 8 gives the specific heats of mineral glasses.

TABLE 8.—MEAN SPECIFIC HEATS OF SILICATE GLASSES  
g cal<sub>15</sub>/g per °C; *v. also* Table 2

These determinations are the most accurate in the literature and the compositions are well established (64).

Glass	0–100°	0–300°	0–500°	0–700°	0–900°	0–1100°
Anorthite, An						
CaO · Al <sub>2</sub> O <sub>3</sub> · 2SiO <sub>2</sub> ..	0.1881	0.2152	0.2306	0.2406		
Andesine, Ab <sub>1</sub> An <sub>1</sub> ..	0.1932	0.2211		0.2484	0.2615	
Albite, Ab						
Na <sub>2</sub> O · Al <sub>2</sub> O <sub>3</sub> · 6SiO <sub>2</sub> ..	0.1977	0.2238	0.2410		0.2640	
Microcline						
K <sub>2</sub> O · Al <sub>2</sub> O <sub>3</sub> · 6SiO <sub>2</sub> ..	0.1919	0.2163	0.2321	0.2431	0.2515	0.2598
Wollastonite						
CaO · SiO <sub>2</sub> .....	0.1852	0.2078	0.2208	0.2355		
Diopside						
CaO · MgO · 2SiO <sub>2</sub> ..	0.1938	0.2189	0.2333	0.2439		
Magnesium metasilicate						
MgO · SiO <sub>2</sub> .....	0.2040	0.2302	0.2474	0.2598		

## Thermal Conductivity

TABLE 9.—THERMAL CONDUCTIVITY (29)

Ind. No.	Glass type	g-cal cm <sup>-2</sup> sec <sup>-1</sup> (°C, cm <sup>-1</sup> ) <sup>-1</sup>			
		–190°	–73°	0°	100°
3	496/644	1.181	2.532	2.796	3.243
17	516/640	1.195		2.825	
91	613/369	0.865		1.900	
102	649/338	0.851		1.867	
109	754/275	0.807		1.698	1.812
141	516/692	0.877		1.796	2.007

## ELECTRICAL PROPERTIES

TABLE 10.—MAGNETIC SUSCEPTIBILITY (35)

Magnetic susceptibility,  $\kappa$ , in units of 10<sup>6</sup> cgs, as function of magnetic field-strength,  $H$ , in gauss

Ind. No.	$\kappa$			Ind. No.	$\kappa$		
	$H = 1350$	$H = 1800$	$H = 2200$		$H = 1350$	$H = 1800$	$H = 2200$
4	–0.90	–0.90	–0.90	52	–0.93	–0.93	–0.93
11	–0.85	–0.865	–0.885	72	–0.91	–0.92	–0.93
12	–0.93	–0.93	–0.93	75		–0.38	–0.395
35	–0.59	–0.60	–0.607	87	–0.95	–0.95	–0.95
45	–0.78	–0.78	–0.78	105	–1.01	–1.01	–1.01

TABLE 11.—DIELECTRIC PROPERTIES

The factors which measure the value of a dielectric are: (a) dielectric constant,  $\epsilon$ ; (b) dielectric strength, measured by the sparking voltage, and varying with the thickness of material tested; and, (c) the energy taken up by the dielectric, measured either by the phase angle, PA, between displacement current and charging current, or by the power factor,  $PF$ , the cosine of the phase angle.

(a) Dielectric constant,  $\epsilon$ 

Ind. No.	Glass type	$\epsilon$	Lit.	Ind. No.	Glass type	$\epsilon$	Lit.
1	Pyrex	4.83*	(12)	81	604/438	7.71	(54.1)
(Near 2)	464/657	5.81	(54.1)	84	610/574	8.20	(54.1)
17	516/640	6.2	(13)	90	614/564	7.6	(13)
31	520/520	6.92	(54.1)	91	613/369	7.47	(54.1)
37	523/513	4.8	(13)	96	620/362	6.8	(13)
41	537/512	6.7	(13)	107	717/295	8.5	(13)
60	569/426	6.5	(13)	(Near 113)	917/	16.2	(54.1)

\* (50 000 cycles.)

(b) Dielectric strength. Unit: 10<sup>3</sup> volts cm<sup>-1</sup>

Ind. No.	Glass type	Thickness tested, mm	D. S.	Lit.
1	Pyrex	6.35	134	(12)
15	513/573	0.41	429	(13)
		1.42	220	(13)
		2.28	179	(13)
70	576/408	0.41	1000	(13)
136	519/609	1.49	240	(13)
		1.60	252	(13)

## (c) Energy adsorption in dielectric

Ind. No.	Type	PF, %	Ind. No.	Type	PA min
1	Pyrex lab.	0.52	58	570/560	2.81
1a	Pyrex radio	0.18	63	573/575	2.68
		PA min	70	577/414	1.82
(Near 2)	464/656	6.14	84	611/572	1.90
3	501/659	11.46	91	613/369	1.54
17	516/640	6.80	96	620/363	1.39
22	519/604	7.85	102	649/338	1.40
33	526/513	22.6	104	657/363	1.48
38	529/518	2.94	111	778/265	2.60

TABLE 12.—ELECTRICAL RESISTIVITY AND CONDUCTIVITY

## (a) Resistivity

Ind. No. 1, Pyrex: Surface resistivity (12): 10<sup>14</sup> ohm at 34% humidity, 5 × 10<sup>3</sup> ohm at 84% humidity. Volume resistivity (12): 10<sup>14</sup> ohm-cm.

(b) Conductivity,  $\kappa$ . Unit: 10<sup>12</sup> ohm<sup>-1</sup> cm<sup>-1</sup>

Ind. No.	100°	125°	150°	175°	200°	Lit.
12	0.012	0.0703	0.334	1.59	6.90	(6)
23	0.0132	0.0672	0.425	2.32		(6)
44	0.00542	0.0418	0.221	1.57	7.69	(6)
52	0.0190	0.0416	0.0968	0.5076	2.38	(6)
70	0.0025	0.015	0.0684	0.668	2.544	(6)
85	0.00256	0.0134	0.0406	0.106	0.374	(6)
96	0.00233	0.00994	0.039	0.116	0.393	(6)
131	132	462	2 650	8 700	26 300	(6)
132	103	456	1 692	5 854	17 800	(6)
133	542	302	1 400	4 740		(6)

Unit: 10<sup>7</sup> ohm<sup>-1</sup> cm<sup>-1</sup>

Ind. No.	$t^\circ$	$\kappa$	$t^\circ$	$\kappa$	$t^\circ$	$\kappa$	$t^\circ$	$\kappa$	Lit.
6	250	129	402	4008	502	13 000	602	50 000	(5)
8	250	6.77	400	415.8	489	2 100			(5)
122	250	2.5	409	90.8	500	345	600	1 178	(5)

## OPTICAL PROPERTIES

The relations between composition and optical properties in several systematic series are shown in Figs. 29–36. The properties of typical optical glasses are shown in Table 13, which, together with the compositions, was furnished by Chance Bros. and Co., Ltd. Table 14 gives the index for the infra-red and ultra-violet; Table 15, the effect of temperature on index; Table 16, the effect of pressure and strain; and Table 17, the absorption of light by various glasses.

TABLE 13.—DISPERSIONS OF TYPICAL OPTICAL GLASSES (9)

Ind. No.	$n_D$	Mean dispersion $n_F - n_C$	$\nu = \left( \frac{n_D - 1}{n_F - n_C} \right)$	Partial dispersions and relative partial dispersions			Sp. gr.
				D-C	F-D	G'-F	
2	1.4785	0.00682	70.2	0.00202	0.00480	0.00363	2.47
				.296	.704	.532	
5	1.4980	.00763	65.3	.00227	.00536	.00425	2.40
				.298	.702	.557	
9	1.5087	.00793	64.1	.00237	.00556	.00445	2.46
				.299	.701	.561	
18	1.5160	.00809	63.8	.00242	.00567	.00454	2.54
				.299	.701	.561	
10	1.5100	.00821	62.1	.00246	.00575	.00462	2.50
				.299	.701	.562	
79	1.5881	.00962	61.1	.00287	.00675	.00541	3.31
				.298	.702	.563	
20	1.5155	.00848	60.8	.00250	.00598	.00482	2.48
				.295	.705	.568	
27	1.5175	.00856	60.5	.00254	.00602	.00484	2.49
				.297	.703	.565	
29	1.5186	.00860	60.3	.00254	.00606	.00489	2.49
				.295	.705	.569	
89	1.6130	.01025	59.8	.00302	.00723	.00582	3.58
				.294	.706	.568	
43	1.5407	.00910	59.4	.00268	.00642	.00517	2.90
				.295	.705	.568	
86	1.6118	.01037	59.0	.00305	.00732	.00590	3.56
				.294	.706	.569	
16	1.5149	.00890	57.9	.00265	.00625	.00506	2.62
				.298	.702	.569	
66	1.5744	.00995	57.7	.00292	.00703	.00567	3.23
				.293	.707	.570	
90	1.6134	.01090	56.3	.00319	.00771	.00626	3.58
				.292	.708	.575	
94	1.6150	.01097	56.1	.00323	.00776	.00630	3.58
				.292	.708	.575	
77	1.5837	.01041	56.1	.00304	.00737	.00596	3.29
				.292	.708	.573	
58	1.5661	.01029	55.0	.00301	.00728	.00591	3.14
				.293	.707	.574	
37	1.5237	.01003	52.2	.00295	.00708	.00577	2.67
				.294	.706	.575	
50	1.5515	.01067	51.7	.00310	.00757	.00619	2.99
				.291	.709	.581	
40	1.5290	.01026	51.6	.00300	.00726	.00593	2.56
				.292	.708	.578	
49	1.5523	.01075	51.4	.00313	.00762	.00624	3.06
				.291	.709	.581	
76	1.5833	.01251	46.6	.00362	.00889	.00738	3.30
				.289	.711	.590	
53	1.5534	.01201	46.1	.00347	.00854	.00711	2.96
				.289	.711	.592	
46	1.5472	.01196	45.8	.00348	.00848	.00707	2.93
				.291	.709	.591	
48	1.5491	.01206	45.5	.00348	.00858	.00714	2.95
				.289	.711	.592	
56	1.5677	.01291	44.0	.00371	.00920	.00763	3.08
				.288	.712	.591	
55	1.5632	.01312	42.9	.00375	.00937	.00781	3.07
				.286	.714	.595	
69	1.5746	.01388	41.4	.00396	.00992	.00830	3.18
				.285	.715	.598	
72	1.5787	.01420	40.8	.00406	.01014	.00851	3.26
				.286	.714	.599	
93	1.6125	.01655	37.0	.00471	.01184	.01003	3.54
				.285	.715	.606	
92	1.6134	.01662	36.9	.00473	.01189	.01008	3.55
				.285	.715	.606	
97	1.6214	.01722	36.1	.00491	.01231	.01047	3.63
				.285	.715	.608	
104	1.6683	.01876	35.6	.00533	.01343	.01147	3.98
				.284	.716	.611	
101	1.6469	.01917	33.7	.00541	.01376	.01170	3.87
				.282	.718	.610	
106	1.7167	.02430	29.5	.00686	.01744	.01511	4.47
				.282	.718	.622	

The order is that of decreasing  $\nu$ .

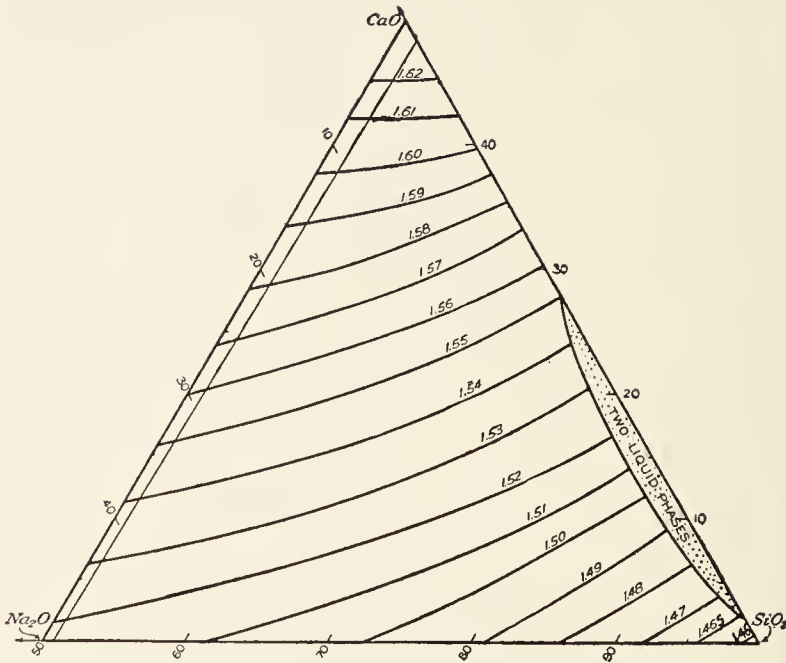


FIG. 29.—Refractive index of Na<sub>2</sub>O-CaO-SiO<sub>2</sub> glasses (41).

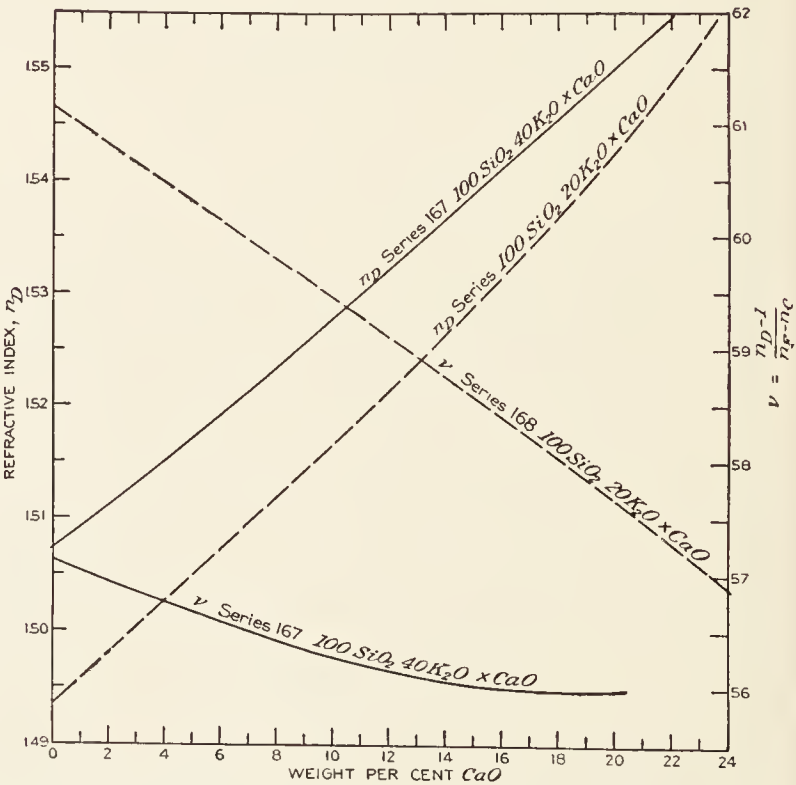


FIG. 30.—Refractive index and  $\gamma$ -value of K<sub>2</sub>O-CaO-SiO<sub>2</sub> glasses of the approximate composition shown (45).



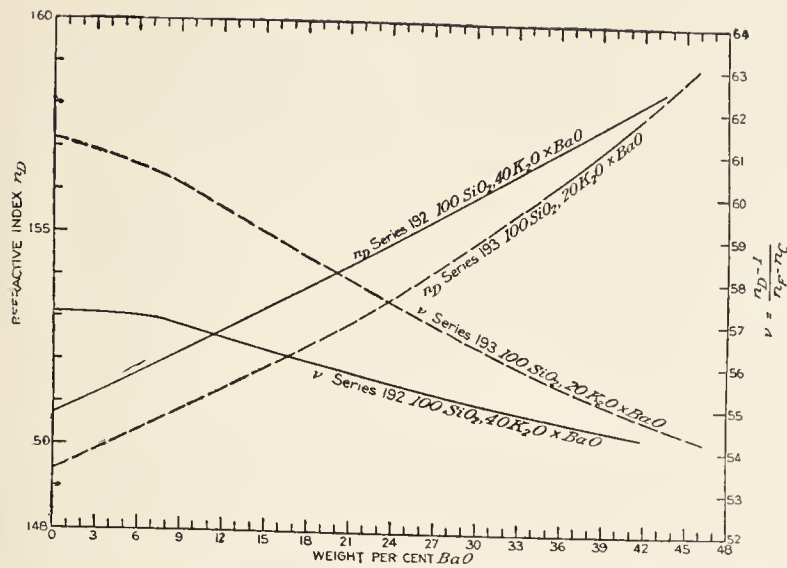


Fig. 31.—Refractive index and  $\gamma$ -value of  $\text{Na}_2\text{O}$ - $\text{BaO}$ - $\text{SiO}_2$  glasses of the approximate composition shown (46).

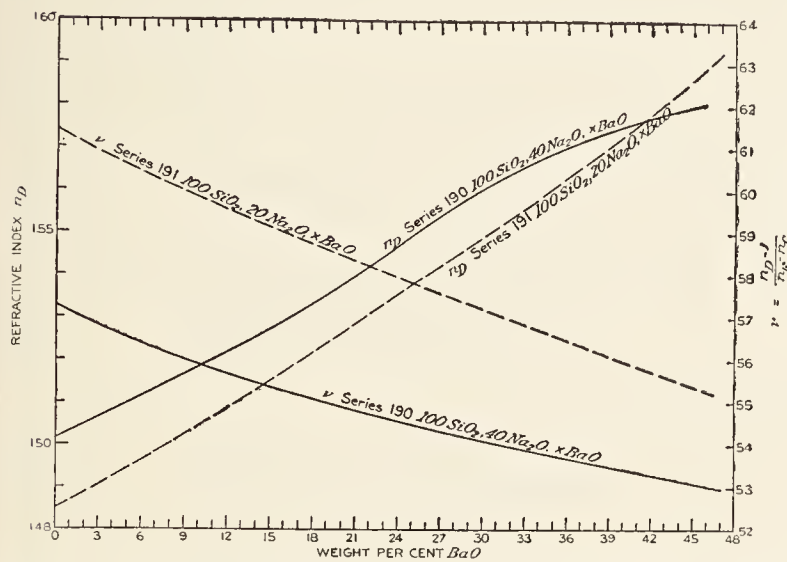


Fig. 32.—Refractive index and  $\gamma$ -value of  $\text{K}_2\text{O}$ - $\text{BaO}$ - $\text{SiO}_2$  glasses of the approximate composition shown (46).

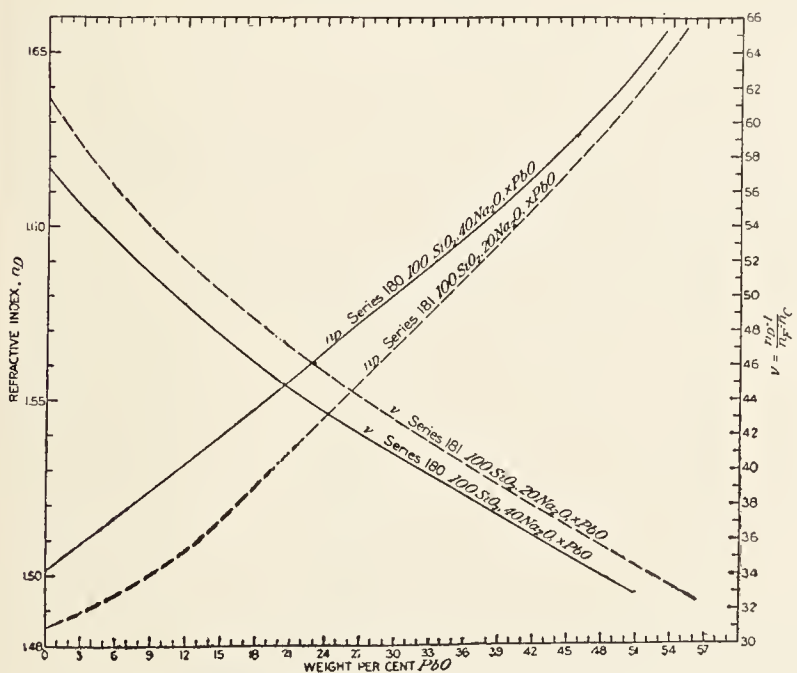


Fig. 33.—Refractive index and  $\gamma$ -value of  $\text{Na}_2\text{O}$ - $\text{PbO}$ - $\text{SiO}_2$  glasses of the approximate composition shown (47).

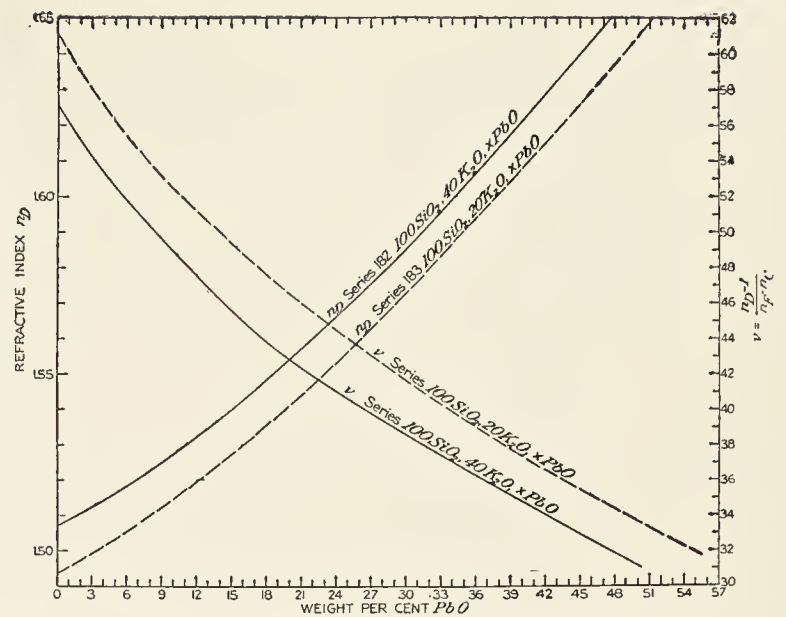


Fig. 34.—Refractive index and  $\gamma$ -value of  $\text{K}_2\text{O}$ - $\text{PbO}$ - $\text{SiO}_2$  glasses of the approximate composition shown (47).

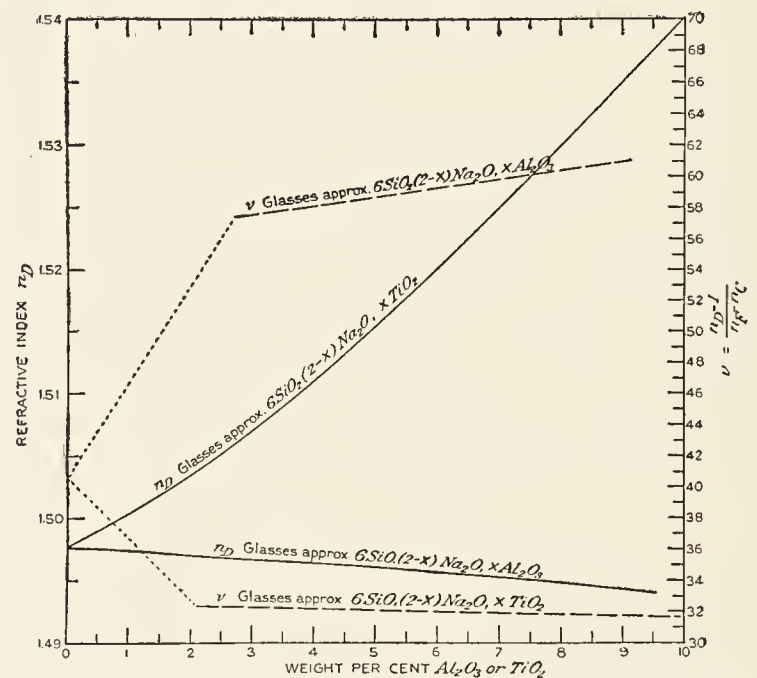


Fig. 35.—Refractive index and  $\gamma$ -value of glasses derived from  $\text{Na}_2\text{O} \cdot 3\text{SiO}_2$  by substitution of  $\text{Al}_2\text{O}_3$  or  $\text{TiO}_2$  for  $\text{Na}_2\text{O}$ . Exact compositions are given in the original (10, 55).

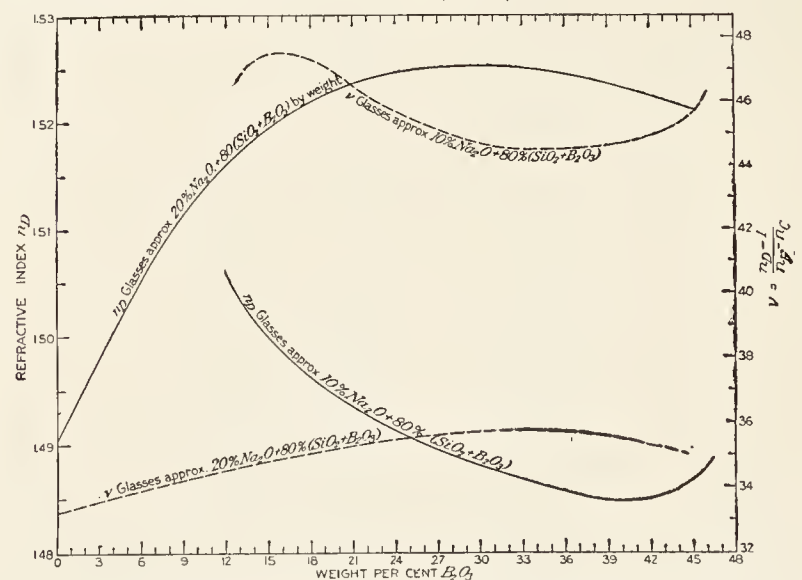


Fig. 36.—Refractive index and  $\gamma$ -value of  $\text{Na}_2\text{O}$ - $\text{B}_2\text{O}_3$ - $\text{SiO}_2$  glasses. Exact compositions are given in the original (28).

TABLE 14.—REFRACTIVE INDICES FOR VARIOUS WAVE LENGTHS

Source	Wave length $\mu\mu$	Index number (from Table 1) and Lit.												
		134(60)	135(53)	12(60)	24(60)	25(60)	31(53)	32(55)	38(60)	39(60)	42(60)	54(60)	144(53)	57(60)
	2200					1.4943								
	2000		1.4845			1.4967	1.4973						1.5390	
	1800		1.4884			1.4988	1.4999						1.5424	
	1600		1.4919			1.5008	1.5024						1.5452	
	1400		1.4950			1.5027	1.5048						1.5476	
	1200		1.4979			1.5048	1.5069						1.5497	
	1000		1.5009			1.5071	1.5096						1.5522	
	800		1.5044			1.5103	1.5131						1.5555	
$K_{\alpha}(A^1)$ .....	768		1.50426			1.51143	1.51368	1.51410					1.55651	
$H_{\alpha}(C)$ .....	656.3	1.50486	1.50742	1.50883	1.51436	1.51446	1.51712	1.51742	1.51932	1.52441	1.53755	1.55771	1.55957	1.56014
$Cd_1$ .....	643.9	1.50525		1.50917	1.51482				1.51979	1.52490	1.53797	1.55821	1.55821	1.56068
$Na(D)$ .....	589.0	1.50734	1.51007	1.51124	1.51693	1.51698	1.52002	1.52046	1.52231	1.52704	1.54025	1.56075	1.56207	1.56343
$Cd_2$ .....	537.9	1.50976		1.51362	1.51957				1.52536	1.52961	1.54297	1.56375		1.56671
$Tl_{\alpha}$ .....	534.9		1.51287			1.51971	1.52327	1.52363					1.56476	
$Cd_3$ .....	533.8	1.51004		1.51386	1.51982				1.52568	1.52989	1.54321	1.56407		1.56689
$Cd_4$ .....	508.6	1.51154	1.51447	1.51534	1.52143	1.52132	1.52525	1.52567	1.52754	1.53146	1.54489	1.56596	1.56643	1.56914
$H_{\beta}(F)$ .....	486.1		1.51610	1.51690		1.52299	1.52715	1.52752	1.52954	1.53303			1.56794	1.57148
$Cd_5$ .....	479.9	1.51362	1.51662	1.51732	1.52361	1.52354	1.52782	1.52824	1.53007	1.53362	1.54714	1.56844	1.56847	1.57193
$Cd_6$ .....	467.8	1.51461	1.51769	1.51828	1.52466	1.52451	1.52903	1.52946	1.53129	1.53464	1.54825	1.56968	1.56949	1.57333
$Cd_7$ .....	441.6	1.51704		1.52066	1.52725				1.53436	1.53721	1.55093	1.57268		1.57667
$H_{\gamma}(G^1)$ .....	434.0	1.51775	1.52092	1.52136		1.52778	1.53312	1.53341	1.53521	1.53790			1.57273	1.57764
$Cd_8$ .....	398.8	1.52210		1.52546	1.53261				1.54075	1.54245	1.55646	1.57896		1.58375
$Cd_9$ .....	361.2	1.52852	1.53195	1.53156	1.53943	1.53897	1.54664	1.54726	1.54897	1.54911	1.56354	1.58704	1.58330	1.59300
$Cd$ .....	353.6	1.53010			1.54111					1.55071	1.56525			1.59526
$Cd_{10}$ .....	346.7	1.53157	1.53509	1.53445	1.54272	1.54215	1.55068	1.55132	1.55300	1.55225	1.56689	1.59093	1.58632	1.59754
$Cd_{11}$ .....	340.4	1.53307	1.53660	1.53586	1.54432	1.54369	1.55262	1.55330	1.55504	1.55379	1.56852	1.59279	1.58776	1.59978
$Cd$ .....	334.5	1.53490							1.55746	1.55564	1.57046	1.59452		1.60248
$Cd_{12}$ .....	328.4	1.53721		1.53982	1.54879				1.56043	1.55804	1.57296	1.59796		1.60593
$Cd$ .....	326.4	1.53811							1.56157					1.60748
$Cd$ .....	326.1		1.54046			1.54755	1.55770	1.55838					1.59138	
$Cd$ .....	323.6	1.53896								1.56004		1.60033		1.60900
$Cd$ .....	322.1	1.53932		1.54168					1.56311	1.56086	1.57511	1.60081		1.61015
$Cd$ .....	321.0			1.54204										
$Cd$ .....	320.2	1.53982		1.54238	1.55089					1.56175	1.57593			1.61189
$Cd$ .....	318.5	1.54079			1.55175				1.56518	1.56193	1.57830	1.60263		
$Cd$ .....	315.7			1.54475	1.55414				1.56675			1.60475		
$Cd_{13}$ .....	313.3		1.54444	1.54536	1.55450	1.55159	1.56307	1.56381		1.56343	1.57870			
$Cd_{14}$ .....	308.1		1.54625	1.54839	1.55875	1.55343	1.56558	1.56632		1.56661	1.58293			
$Cd$ .....	306.5								1.56714	1.56714				
$Cd$ .....	298.0		1.55005			1.55723	1.57093	1.57176						
$Cd$ .....	288.0		1.55437			1.56161								
$Cd$ .....	283.7		1.55648			1.56372								
$Cd$ .....	276.3		1.56027			1.56759								

Source	Wave length $\mu\mu$	Index number (from Table 1) and Lit.												
		68(55)	68(53)	70(54)	71(60)	75(55)	80(60)	84(55)	96(60)	98(60)	102(53)	139(60)	108(53)	112(53)
	2400			1.5440							1.6131			1.8286
	2200			1.5463							1.6150		1.7082	1.8310
	2000		1.5515	1.5487							1.6171		1.7104	1.8316
	1800		1.5541	1.5512							1.6193		1.7127	1.8364
	1600		1.5565	1.5535							1.6217		1.7151	1.8396
	1400		1.5588	1.5559							1.6246		1.7180	1.8433
	1200		1.5611	1.5585							1.6277		1.7215	1.8481
	1000		1.5637	1.5615							1.6315		1.7264	1.8541
	800		1.5673	1.5659							1.6373		1.7339	1.8650
K $\alpha$ (A <sup>1</sup> ).....	768	1.56731	1.56782	1.56669		1.57508		1.60277			1.63820		1.73530	1.86702
H $\alpha$ (C).....	656.3	1.57073	1.57120	1.57119	1.57568	1.57934	1.58848	1.60644	1.61574	1.62285	1.64440	1.65326	1.74368	1.87893
Cd <sub>1</sub> .....	643.9				1.57619		1.58896		1.61656	1.62356		1.65435		
Na(D).....	589.0	1.57363	1.57422	1.57524	1.57893	1.58282	1.59144	1.60956	1.62073	1.62750	1.64985	1.65762	1.75130	1.88995
Cd <sub>2</sub> .....	537.9				1.58211		1.59433		1.62578	1.63226		1.66146		



Source	Wave length $\mu\mu$	Index number (from Table 1) and Lit.												
		68(55)	68(53)	70(54)	71(60)	75(55)	80(60)	84(55)	96(60)	98(60)	102(53)	139(60)	108(53)	112(53)
Tl $\alpha$ .....	534.9	1.57687	1.57746	1.57973		1.58689		1.61292			1.65601		1.75995	1.90262
Cd <sub>3</sub> .....	533.8				1.58244		1.59463		1.62630	1.63274		1.66185		
Cd <sub>4</sub> .....	508.6	1.57883	1.57938	1.58247	1.58444	1.58941	1.59644	1.61504	1.62952	1.63577	1.65979	1.66423	1.76539	
H $\beta$ (F).....	486.1	1.58079	1.58126	1.58515	1.58646	1.59178	1.59825	1.61706			1.66367	1.66670	1.77091	1.91890
Cd <sub>5</sub> .....	479.9	1.58132	1.58188	1.58594	1.58715	1.59257	1.59878	1.61770	1.63396	1.63992	1.66482	1.66742	1.77256	
Cd <sub>6</sub> .....	467.8	1.58253	1.58306	1.58772	1.58848	1.59419	1.59996	1.61891	1.63615	1.64196	1.66725	1.66904	1.77609	
Cd <sub>7</sub> .....	441.6				1.59174		1.60285		1.64162	1.64704		1.67292		
H $\gamma$ (G <sup>1</sup> ).....	434.0	1.58651	1.58710	1.59355	1.59268	1.59920	1.60367	1.62320	1.64319		1.67561	1.67436	1.78800	1.94493
Cd <sub>8</sub> .....	398.8				1.59852		1.60870		1.65333	1.65792		1.68104		
Cd <sub>9</sub> .....	361.2	1.59951	1.60022	1.61388	1.60726	1.61691	1.61622	1.63683	1.66933	1.67269	1.70536	1.69146	1.83263	
Cd.....	353.6				1.60937		1.61800		1.67346			1.69400		
Cd <sub>10</sub> .....	346.7	1.60326	1.60399	1.62008	1.61148	1.62228	1.61978	1.64077	1.67753	1.68018	1.71485	1.69648	1.84731	
Cd <sub>11</sub> .....	340.4	1.60510	1.60583	1.62320	1.61356	1.62492	1.62148	1.64271	1.68160	1.68390	1.71968	1.69892	1.85487	
Cd.....	334.5				1.61559		1.62356		1.68685	1.68838		1.70135		
Cd <sub>12</sub> .....	328.4				1.61922		1.62622		1.69265	1.69454		1.70408		
Cd.....	326.4				1.62069				1.69356			1.70562		
Cd.....	326.1	1.60973	1.61045	1.63134		1.63166		1.64754			1.73245			
Cd.....	323.6				1.62159									
Cd.....	322.1													
Cd.....	321.0													
Cd.....	320.2				1.62256									
Cd.....	318.5				1.62311									
Cd.....	315.7				1.62462									
Cd <sub>3</sub> .....	313.3	1.61446	1.61525	1.64024	1.62678	1.63908		1.65254	4.12	1.6688	936	1.7276		
Cd <sub>4</sub> .....	308.1	1.61664	1.61744	1.64453		1.64258			3.83	1.6758	769.93	1.735000		
Cd.....	306.5								3.56	1.6821	656.33	1.743488		
Cd.....	298.0	1.62122	1.62213	1.65397					3.24	1.6885	589.32	1.751094		
Cd.....	288.0	1.62642	1.62742						2.98	1.6934	534.96	1.759751		
Cd.....	283.7	1.62893	1.62997						2.71	1.6980	486.16	1.770658		
Cd.....	276.3								2.40	1.7029	434.09	1.787782		
									2.02	1.7086	404.44	1.801758		
									1.625	1.7144				
									1.216	1.7208				

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Wave length $\mu$	$n$	Wave length $\mu\mu$	$n$
4.12	1.6688	936	1.7276
3.83	1.6758	769.93	1.735000
3.56	1.6821	656.33	1.743488
3.24	1.6885	589.32	1.751094
2.98	1.6934	534.96	1.759751
2.71	1.6980	486.16	1.770658
2.40	1.7029	434.09	1.787782
2.02	1.7086	404.44	1.801758
1.625	1.7144		
1.216	1.7208		

TABLE 15.—EFFECT OF CHANGE IN TEMPERATURE ON THE ABSOLUTE REFRACTIVE INDEX OF GLASS

Ind. No.	Type	Mean temp.	Change in refractive index, $10^5 \Delta n / \Delta t$ $\Delta t = \pm 50^\circ$				
			C	D	F	G'	Lit.
14	513/637	52.8	+0.119	+0.137	+0.178	+0.213	(51)
23	517/602	59.3	-0.129	-0.105	-0.060	-0.010	(51)
45	545/503	59.2	+0.267	+0.299	+0.356	+0.410	(51)
60	571/430	58.0	+0.226	+0.250	+0.307	+0.360	(52)
		149.6	+0.324	+0.362	+0.456	+0.548	
		251.5	+0.509	+0.568	+0.666	+0.768	
		351.5	+0.577	+0.639	+0.751	+0.870	
		436.5	-1.861	-1.720	-1.504	-1.329	
61	572/504	56.5	+0.014	+0.045	+0.107	+0.150	(52)
		157.1	0.094	0.111	0.179	0.246	
		261.5	0.144	0.167	0.249	0.355	
		357.0	0.217	0.249	0.350	0.461	
63	573/576	61.2	0.024	0.035	0.092	0.099	(52)
		154.0	0.096	0.113	0.152	0.186	
		257.0	0.156	0.174	0.223	0.258	
		358.0	0.221	0.247	0.297	0.340	
84	610/574	55.9	0.394	0.410	0.504	0.528	(52)
		148.0	0.419	0.444	0.543	0.517	
		251.0	0.455	0.489	0.603	0.629	
		356.5	0.509	0.555	0.648	0.682	

TABLE 15.—EFFECT OF CHANGE IN TEMPERATURE ON THE ABSOLUTE REFRACTIVE INDEX OF GLASS.—(Continued)

Ind. No.	Type	Mean temp.	Change in refractive index, $10^5 \Delta n / \Delta t$ $\Delta t = \pm 50^\circ$				
			C	D	F	G'	Lit.
91	613/369	55.1	0.244	0.281	0.389	0.503	(51)
109	755/275	57.7	0.703	0.778	1.058	1.294	(52)
		126.0	0.916	1.051	1.302	1.668	
		176.5	0.960	1.092	1.430	1.714	
		231.0	1.127	1.237	1.632	1.993	
		280.5	1.277	1.396	1.790	2.140	
		325.0	1.382	1.544	1.960	2.405	
		379.0	1.758	1.904	2.263	2.893	
112	890/226	60.5	1.119	1.278	1.752	2.161	(52)
		125.5	1.275	1.442	1.959	2.477	
		177.5	1.379	1.594	2.098	2.617	
		250.5	1.577	1.783	2.396	2.992	
		330.0	1.808	2.027	2.753		
114	963/197	62.6	1.218	1.472	2.110	2.800	(52)
		156.2	1.579	1.809	2.536		
		233.0	1.928	2.251	3.212		
		281.0	1.591	1.911	2.918		
134	507/604	60	-0.066	-0.074	-0.033	-0.003	(51)
141	516/703	58.1	-0.202	-0.190	-0.168	-0.142	(51)
145	562/665	60.3	-0.314	-0.305	-0.246	-0.237	(51)

TABLE 16.—EFFECT OF PRESSURE ON OPTICAL PROPERTIES

The birefringence produced by a thrust  $F$  is measured in terms of the difference in index for white light of the two rays:  $n_y - n_z = BF$ , in which  $B = \frac{n}{2R} \left( \frac{q}{v} - \frac{p}{v} \right)$ , in which  $R$  = rigidity,  $q$  and  $\frac{p}{v}$  optical coefficients. The effect of uniform pressure,  $P'$ , can be calculated from the equation  $\frac{n_x - n}{n} = \frac{P'}{E} (1 - 2\sigma) \left( \frac{2p}{v} + \frac{q}{v} \right)$ , in which  $E$  and  $\sigma$  are Young's modulus and Poisson's ratio. Unit of  $F$  =  $10^{-13}$  barye.

Ind. No.	Type	$F$	$p/v$	$q/v$	Lit.
19	516/620	-2.79			(1)
36	523/590	-2.52			(1)
41	537/512	-2.66			(30)
45	545/503	-3.70	0.239	0.182	(50)
60	571/430	-2.87	0.306	0.213	(50)
65	573/420	-3.13			(1)
67	574/570	-2.75			(1)
82	606/440	-3.03			(1)
83	608/570	-2.10			(1)
95	616/370	-3.06			(1)
96	621/361	-2.77			(30)
100	645/341	-2.56	0.335	0.264	(50)
103	655/330	-2.61			(1)
105	680/317	-2.17			(30)
107	717/295	-1.70			(30)
108	751/276	-1.30	0.354	0.319	(50)
110	756/270	-1.19			(1)
114	963/197	+1.88	0.427	0.466	(50)
134	507/614	-4.23	0.274	0.166	(50)

TABLE 17a.—TRANSMISSION FACTOR

$A = I/I_0$  ( $v$ . vol. I, p. 34); ultraviolet region; wave length,  $\lambda$ , in  $\mu\mu$ ; In. = Index number of glass

Glass thickness, 1 mm (<sup>36</sup>)

In. $\lambda$	12	23	39	52	71	81	84	98	99	105
384					0.995	0.986	0.989	0.983	0.985	0.947
361	0.995	0.995	0.994		.984	.962	.958	.952	.959	.83
347	.988	.991	.983	0.988	.959	.925	.88	.92	.89	.64
330	.957	.974	.938	.959	.89	.75	.76	.71	.74	.33
309	.78	.70	.69	.65						

Glass thickness, 10 mm (<sup>36</sup>)

In. $\lambda$	12	23	39	52	71	81	84	98	99	105
434					0.969					
425	0.993	0.982	0.970	0.978	.961	0.963	0.965	0.952	0.961	0.905
415	.982		.968	.973	.965					
406			.964		.974					
396	.986	.981	.980	.987	.971	.931	.941	.917	.944	.76
384	.972	.975	.955	.968	.948	.865	.894	.84	.86	.58
361	.950	.949	.942	.952	.849	.68	.65	.61	.66	.16
347	.88	.91	.85	.88	.66	.46	.28	.41	.30	.01
330	.65	.77	.53	.66	.32	.06	.07	.03	.05	0
309	.08	.03	0	.02	.01	0	0	0	0	0

Glass thickness, 100 mm (<sup>36</sup>)

In. $\lambda$	12	23	39	52	71	81	84	98	99	105
480	0.95	0.97	0.93	0.96		0.94		0.94	0.94	0.89
468	0.94	0.93	0.91	0.94		0.86		0.87	0.95	0.83
448	0.93	0.92	0.81	0.89		0.79		0.79	0.83	0.63
434					0.73					
425	0.94	0.83	0.74	0.80	0.67	0.68	0.70	0.61	0.67	0.67
415	0.84		0.72	0.76	0.70					
406			0.70		0.77					
396	0.87	0.82	0.82	0.88	0.74	0.49	0.54	0.42	0.56	0.06
384	0.75	0.78	0.63	0.72	0.59	0.23	0.33	0.18	0.22	0
361	0.60	0.60	0.55	0.61	0.19	0.02	0.13	0.01	0.01	
347	0.92	0.38	0.19	0.29	0.02	0	0	0	0	
330	0.01	0.07	0	0.02	0					

Ind. No. 1, pyrex, 1 mm thick (<sup>12</sup>)

$\lambda$	396	384	361	347	330	309	280
$A$	1.00	0.97	0.93	0.85	0.70	0.50	0.05

TABLE 17b.—FACTOR (1-A)

Absorption for 1 cm path for the visible spectrum (<sup>49</sup>)

Ind. No.	Type	Wave length in $\mu\mu$					
		357	388	415	442	500	640
12	510/640	4.7	2.5	1.2		0.7	0.5
23	518/602	3.4	2.5	1.8	1.4	0.5	0.3
38	523/513	49	30	12	3.6	0.7	0.7
59	568/530	9	6	2.7		1.6	
75	583/464	18	8.6	2.5	2.1	0.9	0.5
84	611/572	35	9.8	5.2	3.4	2.5	1.6
96	620/362	28	9.6	4.1		0.0	0.0
100	649/338	41	28	6.9		0.9	0.5

TABLE 17c.—ABSORPTION CONSTANT,  $k$ , ( $I = I_0 e^{-kd}$ ) FOR THE INFRA-RED SPECTRAL RANGE (<sup>53</sup>)

Ind. No.	Wave length in $\mu$										
	0.7	0.95	1.1	1.4	1.7	2.0	2.3	2.5	2.7	2.9	3.1
25	0.01	0.04	0.05	0.01	0.01	0.09	0.20	0.34	0.51	0.73	1.24
31	0.02		0.01	0.01	0.02	0.06	0.11	0.23	0.29	0.79	1.15
68	0.02		0.03		0.05	0.07	0.11	0.17	0.34	0.75	1.31
70	0.00		0.01		0.02	0.05	0.08	0.18	0.25	0.62	1.09
102	0.00		0.02		0.01	0.02	0.02	0.03	0.11	0.41	0.69
108	0.00		0.00		0.00		0.00	0.01	0.08	0.30	0.63
112	0.00		0.02		0.01		0.01		0.06	0.25	0.51
135	0.00	0.01	0.06	0.10	0.16	0.21	0.37	0.85	1.25	1.73	
144		0.02	0.05	0.10	0.18	0.40	0.71	0.14	1.69		

## LITERATURE

(For a key to the periodicals see end of volume)

- (1) Adams and Williamson, *143*, **190**: 597, 835; 20. (2) van Agt and Onnes, *64V*, **34**: 618; 25. (3) Allen and Zies, *38*, **1**: 739; 18. (4) Ambronn, *8*, **58**: 139; 19. *63*, **19**: 401; 18. (5) Baumeister, *Diss.*, Rostock, 1912. (6) Bolle, *Diss.*, Berlin, 1900. (7) Branson, *54*, **34**: 471; 15. (8) Cauwood, English and Turner, *105*, **1**: 153; 17. (9) Chance Bros. and Co. Ltd., Smethwick, Birmingham, England, O.
- (10) Clarke and Turner, *105*, **5**: 119; 21. (10.1) Clarke and Turner, *105*, **3**: 260; 19. (11) Cooper, Shaw and Loomis, *11*, **42**: 461; 09. (12) Corning Glass Co., Corning, N. Y., O. (13) Eckert, *200*, **20**: 93; 23. (14) English, *105*, **8**: 265; 24. (14.1) English, *105*, **9**: 83; 25. (15) English, Hodkins, Muirhead and Turner, *105*, **4**: 387; 20. (16) English and Turner, *105*, **3**: 125; 19. (16.1) English and Turner, *105*, **3**: 238; 19. (17) English and Turner, *105*, **3**: 278; 19. (18) English and Turner, *105*, **4**: 115; 20. (19) English and Turner, *105*, **4**: 126; 20.
- (20) English and Turner, *105*, **4**: 153; 20. (21) English and Turner, *105*, **5**: 115; 21. (22) English and Turner, *105*, **5**: 121; 21. (23) English and Turner, *105*, **5**: 183; 21. (24) English and Turner, *105*, **5**: 277; 21. (25) English and Turner, *105*, **5**: 357; 21. (26) English and Turner, *105*, **6**: 228; 22. (27) English and Turner, *105*, **7**: 73; 23. (28) English and Turner, *105*, **7**: 155; 23. (29) Eucken, *8*, **34**: 185; 11.
- (30) Filon, *201*, **12**: 313; 04. (31) Gray, Gray and Dobbie, *5*, **36**: 488; 84. (32) Griffith, *62*, **221**: 162; 20. (33) Harris, *5*, **106**: 718; 24. (34) Hovestadt-Everett, *Jena Glass* (New York, Macmillan), 1902. (35) Königsberger, *8*, **66**: 698; 96. (36) Krüss, *243*, **23**: 197, 229; 03. (37) Lecrenier, *28*, **33**: 119; 24. (38) Littleton, *2*, **22**: 510; 23. (39) Morey and Bowen, *105*, **9**: 226; 25.
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## CHEMICAL DURABILITY OF GLASSES

W. E. S. TURNER

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## INTRODUCTION

In the measurement of the durability of glasses, results may be duplicated with an accuracy of 5 to 10 % only. In a series of glasses of similar composition, the results with the more durable glasses may be reproduced with an accuracy of 5 %; the less durable, up to about 10 %.

## INTRODUCTION

Les résultats ne peuvent être reproduits, dans les mesures de durabilité des verres, qu'avec une précision de 5 à 10 % seulement. Dans les séries de verres de composition similaire, les résultats concernant les verres les plus durables peuvent être reproduits avec une précision de 5 %; ceux relatifs aux verres les moins durables, jusqu'à environ 10 %.

## EINLEITUNG

Die Messungsergebnisse über die Dauerhaftigkeit der Gläser lassen sich nur mit einer Genauigkeit von 5 bis 10 % angeben. In einer Reihe von Gläsern ähnlicher Zusammensetzung können die Ergebnisse mit dauerhafteren Gläsern auf 5 %, mit weniger dauerhaften bis gegen 10 % Genauigkeit angegeben werden.

## INTRODUZIONE

I risultati ottenuti nelle misure di resistenza chimica dei vetri, sono riproducibili con una approssimazione del 5-10 % soltanto. In una serie di vetri di composizione simile, i valori riferentisi ai vetri più resistenti sono riproducibili con l'approssimazione del 5 %, e quelli riguardanti i vetri meno resistenti con una approssimazione del 10 %.

## EFFECT OF COMPOSITION

TABLE 1.—FUSED-QUARTZ GLASS

Milligrams loss in wt. sustained in each test by a 76 cm<sup>3</sup> quartz flask, with 89 cm<sup>2</sup> surface exposed, when subjected in succession to the following reagents under the conditions shown (35); cf. (53).

Reagent, time and temperature			Loss mg
H <sub>2</sub> O, 18°-100°.....	Many	Days at 18°	0.0
10 % NH <sub>3</sub> .....	2		0.8
10 % NaOH.....	2		0.4
30 % NaOH.....	2		0.0*
30 % KOH.....	4		1.2†
2N NaOH.....	3	Hours at 100°	48
2N Na <sub>2</sub> CO <sub>3</sub> .....	3		12
2N KOH.....	3		31
2N NaOH.....	3		33
2N Na <sub>2</sub> CO <sub>3</sub> .....	3		8
2N KOH.....	3	}	64
2N NaOH.....	3		
N NaOH.....	14	Hours at 18°	2
N NaOH.....	14		1.8
N Na <sub>2</sub> CO <sub>3</sub> .....	14		0.6
Satd. Ba(OH) <sub>2</sub> .....	14		0
Satd. Na <sub>2</sub> SO <sub>4</sub> .....	14		0
N H <sub>3</sub> PO <sub>4</sub> .....	14		0
10 % NH <sub>3</sub> .....	14		0
25 % NH <sub>3</sub> .....	60		0
25 % NH <sub>3</sub> , Fresh flask. Up to 60° with 4 renewals of reagent during experiment, 6 hrs.....			2.6

\* No adsorption of NaOH.

† Adsorbed KOH difficult to remove by washing.

Remarks: Ba(OH)<sub>2</sub>, 6 mo. at 18°, small crystals of Ba silicate formed. H<sub>3</sub>PO<sub>4</sub> at 400°, extensive corrosion with formation of silicic phosphate. Dilute acids in general, and conc. H<sub>2</sub>SO<sub>4</sub>,

18-100°, no action. Aqueous *methylene blue*, *congo red*, and *rhodamine*; ethereal *iodococin*; and alcoholic *aniline blue*; all slightly adsorbed but removable by hot solvents.

TABLE 2.—CAO · SiO<sub>2</sub> WOLLASTONITE

Milligrams oxides extracted from 2 g by acids (17, 30, 33, 38).

Oxide	Acid	30 min at 18°	2N			2 hrs at 50°-60°	10N	
			Acetic	HCl	HCl		HCl	HCl
mg CaO			0.010	0.017	0.11		0.70	0.76
mg SiO <sub>2</sub>			0.000	0.004	0.040		0.26	0.020

## 3- (or 4-) Oxide Glasses

TABLE 3

Grams H<sub>2</sub>SO<sub>4</sub> equivalent to the alkali extracted by water at 80° acting for 1 hr on glass powder, size <160 mesh/in. (38, 41, 42, 43)

1. Molecular composition: 100SiO <sub>2</sub> + 40R <sub>2</sub> O + xRO									
x	40Na <sub>2</sub> O + xCaO	40K <sub>2</sub> O + xCaO	20Na <sub>2</sub> O + 20K <sub>2</sub> O + xCaO	40Na <sub>2</sub> O + xPbO	40K <sub>2</sub> O + xPbO	20Na <sub>2</sub> O + 20K <sub>2</sub> O + xPbO	40Na <sub>2</sub> O + xBaO	40K <sub>2</sub> O + xBaO	20Na <sub>2</sub> O + 20K <sub>2</sub> O + xPbO
5	18.4	28.3	30.2	31.6		31.2	37.7	34.0	34.0
10	9.0	27.6	15.3	9.3		19.0	4.54	31.2	21.6
15	4.3	20.4	4.42	4.2		18.2	4.44	27.8	7.6
20	3.7	8.6	3.26	3.4	23.0	6.6	4.25	24.6	6.2
30	2.3	5.1	2.08	1.68	19.0	3.2	1.85	17.4	3.8
40	1.06	2.2	1.05	1.04	8.9	1.50	1.08	9.5	2.8

TABLE 3.—(Continued)

2. Molecular composition: $100\text{SiO}_2 + 20\text{R}_2\text{O} + x\text{RO}$									
$x$	$20\text{Na}_2\text{O} + x\text{CaO}$	$20\text{K}_2\text{O} + x\text{CaO}$	$10\text{Na}_2\text{O} + 10\text{K}_2\text{O} + x\text{CaO}$	$20\text{Na}_2\text{O} + x\text{PbO}$	$20\text{K}_2\text{O} + x\text{PbO}$	$10\text{Na}_2\text{O} + 10\text{K}_2\text{O} + x\text{PbO}$	$20\text{Na}_2\text{O} + x\text{BaO}$	$20\text{K}_2\text{O} + x\text{BaO}$	$10\text{Na}_2\text{O} + 10\text{K}_2\text{O} + x\text{PbO}$
5	3.03	5.4	1.99		9.6	3.32		10.4	2.44
10	1.34	1.44	0.94	0.69	3.7	1.15	1.20	2.01	1.50
15	0.66	0.96	0.66	0.51	1.61	0.68	1.07	1.76	1.21
20	0.40	0.60	0.40	0.37	0.60	0.37	0.87	1.08	1.03
30	0.34	0.36	0.26	0.140	0.26	0.16	0.55	0.74	0.87
40	0.25	0.30	0.24	0.091	0.15	0.12	0.50	0.64	0.68

TABLE 4

Grams oxide extracted by water at  $100^\circ$  acting for 5 hr on 100 g glass powder, containing 7300 to 7624 particles per  $\text{cm}^3$  (30, 32).

Molecular composition: $6\text{SiO}_2 + (2 - x)\text{R}_2\text{O} + x\text{RO}$										
Oxide extracted	Comp. $6\text{SiO}_2 +$	$2\text{Na}_2\text{O}$	$2\text{K}_2\text{O}$	$1.75\text{Na}_2\text{O} + 0.25\text{CaO}$	$1.75\text{K}_2\text{O} + 0.25\text{CaO}$	$1.5\text{Na}_2\text{O} + 0.5\text{CaO}$	$1.5\text{K}_2\text{O} + 0.5\text{CaO}$	$1.25\text{Na}_2\text{O} + 0.75\text{CaO}$	$1.25\text{K}_2\text{O} + 0.75\text{CaO}$	$\text{Na}_2\text{O} + \text{CaO}$
$\text{R}_2\text{O}$ .....		4.4	12.6	1.07	8.84	0.18	0.83	0.06	0.14	0.02
$\text{SiO}_2$ .....		11.3	22.6	1.66	15.82	0.04	0.34	0.03	0.03	0.02
Total.....		15.7	35.2	2.67	24.66	0.22	1.17	0.09	0.17	0.04

TABLE 5

Grams of oxides extracted at  $100^\circ$  in 5 hr by the action of  $60\text{ cm}^3\text{ H}_2\text{O}$  on powdered glass, 4000 particles per  $\text{cm}^3$  (21, 22, 58).

Molecular composition: $x\text{SiO}_2 + y\text{R}_2\text{O} + z\text{RO} + w\text{R}_2\text{O}_2$							
Composition. Wt. %				Grams oxide extracted			
$\text{SiO}_2$	$\text{Na}_2\text{O}$	$\text{RO}$	$\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$	$\text{SiO}_2$	$\text{Na}_2\text{O}$	$\text{RO}$	Total
73.7	22.5		4.0	4.25	1.47		5.80
69.6	22.0	5.1	3.5	1.84	0.716	0.0191	2.60
70.0	17.7	9.9	2.7	0.061	0.098	trace	0.159
68.0	14.8	15.7	1.7	0.024	0.035	trace	0.058
66.7	11.8	19.6	1.9	0.0134	0.018	trace	0.031
69.6	19.3	7.6	3.8	2.74	0.97	0.0515	3.82
67.5	16.2	14.2	2.4	0.236	0.168	trace	0.415
62.2	9.6	25.6	2.9	0.026	0.109	trace	0.134

TABLE 6

Per cent  $\text{Na}_2\text{O}$  extracted by boiling water in 1 hr acting on powdered glass, 20–30 mesh (I. M. M. sieves, v. p. 329) (11, 12, 44, 47, 48, 49).

Molecular composition: $100\text{SiO}_2 + (33.3 - x)\text{Na}_2\text{O} + x\text{RO}$ ( $\text{R}_2\text{O}_3$ or $\text{RO}_2$ )							
$x$	$\text{CaO}$	$\text{MgO}$	$\text{Al}_2\text{O}_3$	$\text{TiO}_2$	$\text{ZrO}_2$	$\text{ZnO}$	$\text{BaO}$
0.5							
1.0					4.4		
2.0	8.20			1.54	1.8	7.18	17.60
4.0	2.35	1.39	0.59	0.27	0.38	1.57	5.50
6.0	1.00	0.76	0.24	0.13	0.19	0.30	1.90

TABLE 6.—(Continued)

$x$	$\text{CaO}$	$\text{MgO}$	$\text{Al}_2\text{O}_3$	$\text{TiO}_2$	$\text{ZrO}_2$	$\text{ZnO}$	$\text{BaO}$
8.0	0.50	0.29	0.09	0.07		0.18	0.68
10	0.25	0.13	0.03	0.045		0.12	0.22
12	0.10	0.07		0.03		0.06	0.12
14	0.05	0.048		0.02		0.04	0.06
16	0.04	0.028		0.012		0.02	0.04
18	0.02	0.020		0.010			
20				0.008			

TABLE 7

Per cent loss in weight in 1 hr in boiling 20.24%  $\text{HCl}$ , 2N  $\text{NaOH}$  and 2N  $\text{Na}_2\text{CO}_3$  acting on powdered glass 20–30 mesh (I. M. M. sieves) (12).

Molecular composition: $100\text{SiO}_2 + (33.3 - x)\text{Na}_2\text{O} + x\text{RO}$											
	$x$	2	4	6	8	10	12	14	16	18	20
$\text{HCl}$	$\text{CaO}$		8.2	4.2	2.6	1.7	1.2	1.0	1.0		
	$\text{MgO}$		1.4	0.7	0.4	0.3	0.2	0.2	0.1		
	$\text{Al}_2\text{O}_3$		0.9	0.4	0.2	0.2					
	$\text{TiO}_2$	2.0	1.0	0.5	0.3	0.2	0.2	0.2	0.1	0.1	0.1
	$\text{ZrO}_2$	1.8	0.6	0.4							
	$\text{ZnO}$	1.8	0.9	0.5	0.3	0.2	0.2	0.1	0.1		
	$\text{BaO}$	9.6	2.0	1.0	0.5	0.3	0.2	0.2	0.2		
$\text{NaOH}$	$\text{CaO}$		2.6	2.3	2.1	2.0	1.7	1.5	1.2		
	$\text{MgO}$		3.1	2.8	2.5	2.7	2.1	2.1	2.1		
	$\text{Al}_2\text{O}_3$		2.8	2.5	2.5	2.6					
	$\text{TiO}_2$		6.0			3.6	3.2	2.9	2.6	2.4	2.3
	$\text{ZrO}_2$	1.3	0.8	0.7							
	$\text{ZnO}$	3.7	3.2	2.8	2.4	2.2	2.1	1.9	1.7		
	$\text{BaO}$	5.6	3.8	3.0	2.5	2.3	2.2	1.9	1.7		
$\text{Na}_2\text{CO}_3$	$\text{CaO}$		6.8	2.8	2.4	2.0	1.9	1.5	1.3		
	$\text{MgO}$			4.1	3.2	2.5	2.1	2.0	1.9		
	$\text{Al}_2\text{O}_3$		1.0	0.6	0.4	0.4					
	$\text{TiO}_2$	11.3	2.4	1.6	1.1	0.9	0.8	0.7	0.7	0.6	0.5
	$\text{ZrO}_2$	2.0	0.9	0.6							
	$\text{ZnO}$	11.2	2.5	0.5	0.4	0.3	0.2	0.2	0.2		
	$\text{BaO}$	38.0	7.0	4.9	4.0	3.5	3.2	2.6	2.2		

TABLE 8

Grams  $\text{H}_2\text{SO}_4$  equivalent to alkali extracted by water at  $80^\circ$  acting for 1 hr on 100 g glass powdered to pass 160 mesh sieve.

1. Composition: $(70 - x)\% \text{SiO}_2 + x\% \text{RO} + y\% \text{R}_2\text{O}$ (39, 42)							
$x$	$\text{RO}$	$25\text{Na}_2\text{O}$	$25\text{K}_2\text{O}$	$12.5\text{Na}_2\text{O} + 12.5\text{K}_2\text{O}$	$20\text{Na}_2\text{O}$	$20\text{K}_2\text{O}$	$10\text{Na}_2\text{O} + 10\text{K}_2\text{O}$
5	$\text{CaO}$	5.32	4.50				
	$\text{PbO}$	34.2	17.5				
	$\text{BaO}$	34.5	21.1	28.2			
10	$\text{CaO}$				1.64	0.75	0.67
	$\text{PbO}$				9.23	11.4	11.5
	$\text{BaO}$	28.8	18.6	22.9	13.3	9.64	7.40
15	$\text{CaO}$	1.98	1.00		1.12	0.60	0.49
	$\text{PbO}$	23.1	17.7		9.81	6.65	3.92
	$\text{BaO}$	22.6	15.8		10.4	7.11	4.87
20	$\text{CaO}$				0.72	0.51	0.40
	$\text{PbO}$				7.89	7.78	3.52
	$\text{BaO}$				8.93	3.47	3.99
25	$\text{CaO}$						
	$\text{PbO}$						
	$\text{BaO}$	14.0	12.7				



TABLE 8.—(Continued)

<i>x</i>	RO	25Na <sub>2</sub> O	25K <sub>2</sub> O	12.5Na <sub>2</sub> O + 12.5K <sub>2</sub> O	20Na <sub>2</sub> O	20K <sub>2</sub> O	10Na <sub>2</sub> O + 10K <sub>2</sub> O
30	CaO						
	PbO				4.88	4.61	3.17
	BaO				2.99	1.77	1.45
40	CaO						
	PbO				4.05	6.65	2.79
	BaO						
50	CaO						
	PbO				4.61	9.16	3.92
	BaO						

<i>x</i>	RO	15Na <sub>2</sub> O	15K <sub>2</sub> O	7.5Na <sub>2</sub> O + 7.5K <sub>2</sub> O	10Na <sub>2</sub> O	10K <sub>2</sub> O	5Na <sub>2</sub> O + 5K <sub>2</sub> O
15	CaO	0.44	0.240	0.22			
	PbO	2.91	1.696				
	BaO	2.68	1.371	1.28			
20	CaO	0.57	0.277		0.29	0.173	0.156
	PbO	2.54	1.610				
	BaO	2.09	0.998				
25	CaO						
	PbO	2.12	.848				
	BaO	1.66					
30	CaO						
	PbO				.45	.208	
	BaO				.68	.575	.337
35	CaO						
	PbO	1.40	.798				
	BaO	1.37					
40	CaO						
	PbO				.30	.163	
	BaO				.69	.563	.536
45	CaO						
	PbO	1.40	.845				
	BaO						
50	CaO						
	PbO				.24	.157	
	BaO						

TABLE 8.—(Continued)

2. Composition: <i>y</i> % SiO <sub>2</sub> + <i>z</i> % PbO + ( <i>a</i> - <i>x</i> ) % Na <sub>2</sub> O + <i>x</i> % K <sub>2</sub> O (19, 40)												
<i>a</i>	<i>y</i>	<i>z</i>	0.0	2.5	5	7	7.5	10	14	15	17.5	20
20	60	20	7.9		4.9			3.5	1.68	2.08	3.8	7.8
20	50	30	4.8		3.6			2.31	1.50	1.63	3.00	4.5
10	60	30	0.43	0.32	0.19	0.122	0.136	0.28				
10	50	40	0.30	0.21	0.123	0.069	0.128	0.175				

TABLE 9

Per cent Na<sub>2</sub>O extracted by boiling H<sub>2</sub>O and % loss in weight by action of boiling 20.24 % HCl, 2*N* NaOH and 2*N* Na<sub>2</sub>CO<sub>3</sub> solns. resp. Time 1 hr. 20-30 mesh powder. The final glasses contained 0.08-0.2 % CaO and 0.05-0.14 % Fe<sub>2</sub>O<sub>3</sub> (12, 49, 50).

Batch	Analytical %				% Na <sub>2</sub> O by H <sub>2</sub> O	% loss in wt. by		
	SiO <sub>2</sub>	B <sub>2</sub> O <sub>3</sub>	Na <sub>2</sub> O	Al <sub>2</sub> O <sub>3</sub>		HCl	NaOH	Na <sub>2</sub> CO <sub>3</sub>
(80 - <i>x</i> ) % SiO <sub>2</sub> + <i>x</i> % B <sub>2</sub> O <sub>3</sub> + 20 % Na <sub>2</sub> O	79.8		19.5	0.69	2.11	1.40	2.92	6.35
	74.2	4.5	19.8	0.93	0.16	0.33	3.16	2.73
	71.6	8.3	18.8	1.00	0.06	0.31	3.10	2.64
	68.3	11.4	19.0	1.09	0.04	0.30	3.46	3.16
	64.7	14.5	20.0	0.71	0.07	1.02	4.54	3.70
	61.3	18.8	18.9	0.74	0.14	7.36	5.65	3.84
	50.0	28.8	20.4	0.78	2.25	39.4	17.2	17.1
	35.2	40.0	23.7	0.84	11.6	38.9	69.7	45.6
(90 - <i>x</i> ) % SiO <sub>2</sub> + 10 % B <sub>2</sub> O <sub>3</sub> + 10 % Na <sub>2</sub> O	32.2	43.7	23.1	0.82	14.7	39.1	94.6	56.1
	74.9	12.5	11.3	0.92	0.004	0.09	3.11	1.40
	70.8	18.7	9.8	0.79	0.07	0.67	4.73	3.10
	67.2	21.8	10.1	0.88	0.36	2.73	7.01	4.29
	62.0	25.8	11.2	0.84	0.89	32.7	22.1	15.2
	57.9	31.3	9.6	0.98	2.42	41.0	62.1	38.6
	52.1	36.2	10.3	0.89	5.50	49.0		54.3
	46.3	42.3	10.4	0.80	7.46	49.3		64.4
(90 - <i>x</i> ) % SiO <sub>2</sub> + 10 % B <sub>2</sub> O <sub>3</sub> + 10 % Na <sub>2</sub> O	41.3	46.1	11.5	0.80				72.8

## MULTI-OXIDE GLASSES. APPARATUS GLASS

In the tables of durability data for these glasses, the glasses are identified by means of the Index Numbers (I. N.) given in Table 10. Additional literature (1, 6, 10, 14, 18, 20, 23, 24, 25, 31, 32, 34, 35, 36, 54, 55, 57).

TABLE 10.—COMPOSITION IN MOLECULES PER 100 MOLECULES SiO<sub>2</sub>

I. N.	Origin	B <sub>2</sub> O <sub>3</sub>	As <sub>2</sub> O <sub>5</sub>	Sb <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub> + Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	ZnO	PbO	Na <sub>2</sub> O	K <sub>2</sub> O	MnO	Lit.
C/1		14.37			4.09					14.79		0.06	(18)
C/2					2.84	10.31		5.07		13.06		0.35	(18)
C/3					0.23	14.68				9.70	4.87		(18)
C/4					0.46	13.28				8.47	5.49		(18)
C/5					0.30	13.95				8.07	5.15	0.22	(18)
C/6					0.23	11.37				10.54	5.85		(18)
C/7					0.39	10.84				6.32	10.03		(18)
C/8					0.23	10.77				12.48	3.53		(18)
C/9					0.30	10.68				12.67	3.80		(18)
C/10		2.55			2.18	8.82		7.65		20.09			(18)
C/11					2.42	16.99				19.62	0.54	0.48	(18)
C/12					0.15	7.87				1.22	11.31	0.11	(18)
C/13					1.05	16.14				17.12	1.57		(18)
C/14					0.32	9.83				11.77	8.35	tr.	(18)
C/15					2.74	11.19				19.26	6.20	0.29	(18)
C/16									14.09		14.13		(18)
C/17					2.03	8.57				17.77	4.84	0.46	(18)
C/18					0.39	11.48				7.20	9.87		(15)
C/19					1.44	21.92			0.85	16.78	0.64		(15)
C/20			0.1			BaO 2.91			16.87	0.89	8.87	0.02	(15)

TABLE 10.—COMPOSITION IN MOLECULES PER 100 MOLECULES  $\text{SiO}_2$ .—(Continued)

I. N.	Origin	$\text{B}_2\text{O}_3$	$\text{As}_2\text{O}_5$	$\text{Sb}_2\text{O}_3$	$\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$	$\text{CaO}$	$\text{MgO}$	$\text{ZnO}$	$\text{PbO}$	$\text{Na}_2\text{O}$	$\text{K}_2\text{O}$	$\text{MnO}$	Lit.
C/21					2.39	10.12				17.13	6.11	0.45	(15)
C/22					0.47	11.52				15.35	4.63		(14)
C/23					0.75	14.34				14.47	7.91		
C/24					2.54	11.69				17.66	6.78		
C/25					3.04	10.62				24.18	2.20		
C/26	Jena 1914.....	13.3			5.7	0.13	0.29	13.5		11.00	tr.	tr.	(4)
C/27	Jena 1914.....	14.55			3.99	0.89		12.86		11.95			(26, 27)
					$\text{Al}_2\text{O}_3$	$\text{Fe}_2\text{O}_3$							
C/28	Jena 1920.....	5.33			6.8			BaO 2.33		6.3	0.47		(26, 27)
C/29	British 1916*.....	2.6			8.3		0.20			20.20	4.00		(4)
C/30	British 1916*.....	9.4			5.6	0.05	tr.	10.3		17.40	0.33		(4)
C/31	Duroglass 1916*.....	5.9			5.9	0.04	0.8	4.0		16.80	2.50		(4)
C/32	Moncrieff 1916*.....	9.0			5.8	0.07	0.3	9.7		14.6	1.0		(4)
C/33	Wood Bros. 1916*.....	10.1			9.0	0.06	0.5			15.0	1.6		(4)
C/34	Poulenc Frères 1916...	4.9			0.85	0.07	tr.	7.9		9.0	5.5		(4)
C/35	French 1916.....				0.75	0.05	1.1			23.6	0.6		(4)
C/36	Swedish 1916.....	2.5			0.9	0.08	0.3	3.2		20.3	1.2		(4)
C/37	Italian 1916.....	2.0			0.3	0.07	tr.			17.2	3.0		(4)
C/38	U. S. A. Nonsol 1917...	9.5		0.13	2.25	0.11	7.5	8.05		17.0	0.28	tr.	(7)
C/39	U. S. A. Insolo 1917...	4.95		0.3	0.8	0.18	13.45	4.05		15.5	0.64	tr.	(7)
C/40	U. S. A. Fry 1917.....	10.0	0.07		2.5	0.11	5.55	3.85		14.1	1.25	tr.	(7)
C/41	U. S. A. Pyrex 1917...	12.6	0.23		1.45	0.07	0.5			4.6	0.5	tr.	(7)
C/42	U. S. A. Insol 1917...	2.9		0.2	0.57	0.12	10.05	8.95		14.3	2.9	tr.	(7)
C/43	Macbeth-Evans 1919...	9.03	0.02	0.11	1.30	0.18	0.96	5.47	5.50	14.65	0.27	tr.	(7)
C/44	Greiner & Friedrich Resistance "R".....	4.8		0.47	2.75	0.08	0.33	7.4	9.15	17.05	1.35		(7)
C/45	Köln-Ehrenfeld.....	5.45	0.82	0.4	2.25	0.12	2.85	5.9	10.9	10.8	1.7	tr.	(7)
C/46	Kavalier 1917.....		tr.		0.18	0.05	12.4	0.3		9.35	6.65	tr.	(7)
C/47	German (unmarked)...				0.21	0.07	8.95	0.57		14.3	4.75		(7)
C/48	Hungarian (Zsolna)...				0.23	0.07	12.6	tr.		9.0	6.4	tr.	(7)
C/49	Japanese 1917.....				1.9	0.07	5.3	0.22		22.6	1.2		(7)
C/50	Murano 1922.....	13.63			5.61					8.79			(26, 27)
C/51	Murano 1923 No. 1....	10.28			4.71		8.57			5.16			(26, 27)
C/52	Murano 1923 No. 2....	10.99			3.62		3.30			5.21			(26, 27)
C/53	Murano 1923 No. 3....	11.81			2.94					5.56			(26, 27)

\* Most of the glasses of these makes have been modified and improved since 1916.

TABLE 11.—ACTION OF WATER ON FLASKS

The values given are thousandths mg alkali extracted and mg loss in weight, each for 100  $\text{cm}^2$  surface. The autoclave data at 190° and at 183° respectively are not comparable with one another.

I. N. (17, 28)	Alkali extracted 10 <sup>-3</sup> mg		Auto- clave mg loss 4 hr 190°	I. N. (17, 28)	Alkali extracted 10 <sup>-3</sup> mg		Auto- clave mg loss 4 hr 190°
	8 da 20°	3 hr 80°			8 da 20°	3 hr 80°	
C/1	2.5	2.7	23.7	C/9	17.8	66	67.0
C/2	2.1	6.3		C/10	16.6	65	34.0
C/3	10.7	28.4		C/11	27.0	98	
C/4	8.9	28.2	17.2	C/12			63.0
C/5	13.1	26.8		C/13			37.0
C/6	14.0	56		C/14	32.0	217	
C/7	14.5	45	51.3	C/15	77.0	654	126
C/8	14.9	50		C/16	74.0	356	
C/46	12.5	24.6	(7)	C/48	13.6	29.3	(7)

TABLE 11.—ACTION OF WATER ON FLASKS.—(Continued)

I. N. (4)	Alkali extracted 10 <sup>-3</sup> mg		Milligrams loss in weight				
	8 da 20°	3 hr 80°	3 hr steam			2 hr evap. 100°	Auto- clave 3 hr 183°
			Treatments				
			1st	2nd	3rd		
C/26	1.6	1.9	0.30	0.15	0.05	0.6	26.0
C/29	3.7	7.0	0.30	0.10	0.08	0.9	22.0
C/30	3.1	5.6	0.28	0.15	nil	0.6	23.7
C/31	2.6	6.2	0.25	0.12	0.08	1.05	26.8
C/32	2.3	4.7	0.22	0.04	nil	0.45	20.7
C/33	2.5	4.9	0.25	nil	nil	0.67	18.5
C/34	3.3	6.3	0.24	0.40	0.16	0.52	20.5
C/35	25.7	43.2	4.00	2.23	2.12	8.6	2210
C/36	12.3	24.7	2.13	1.85	1.24	2.1	875.0
C/37	21.7	35.4	2.30	1.75	1.43	4.7	1040



TABLE 11.—ACTION OF WATER ON FLASKS.—(Continued)

I. N.	mg loss in weight		I. N.	mg loss in weight	
	2 hr evap. 100°	Autoclave 3 hr 183°		2 hr evap. 100°	Autoclave 3 hr 183°
C/38	0.8	31.5	C/44	1.05	55.4
C/39	1.05	139	C/45	1.0	48.5
C/40	0.95	48.7	C/46	2.6	614
C/41	0.67	10.0	C/47	0.4	3183
C/42	1.0	79.6	C/48		
C/43	0.3	46.2	C/49	5.4	
Lit.	(7, 24, 29)				

TABLE 12.—ACTION OF ACIDS ON FLASKS

Mean loss in wt. (mg per 100 cm<sup>2</sup> surface) from 3 successive treatments with each reagent. Reagents: A, HCl vapor for 3 hr (4). B, 20.24% HCl evap. for 1.5 hr (4, 7). C, 2N H<sub>2</sub>SO<sub>4</sub> for 6 hr at 100° (17). D, coned. H<sub>2</sub>SO<sub>4</sub> heated to fuming for 4 hr (51). E, 1.2 sp. gr. HNO<sub>3</sub> evap. for 1.5 hr (28, 29, 51). (Cf. Tables 15, 16, 18, and 20.)

R	I. N. C/	26	29	30	31	32	33	34	35	36	37
A		1.59	1.01	0.52	0.36	0.63	2.60	0.37	0.71	0.39	0.73
B		10.6	5.0	3.2	2.4	2.7	11.1	1.7	2.7	1.9	1.8
C		1.2	0.8	0.9	1.3	0.8	0.8	0.8	1.9	1.9	1.3
D					1.0		0.2		1.0		
E					1.0	1.8	1.6				

R	I. N. C/	38	39	40	41	42	43	44	45	46	47
B		1.0	1.0	1.1	0.5	1.1	0.5	0.9	1.4	0.7	0.2

TABLE 13.—ACTION OF ALKALIES ON FLASKS

Loss in wt., mg/100 cm<sup>2</sup> surface.

Reagents: A, 2N NaOH for 3 hr at 100° (17). B, 0.1N NaOH for 3 hr at 100° (17). C, 2N NH<sub>4</sub>OH evap. for 65–70 min (17). D, 2N Na<sub>2</sub>CO<sub>3</sub>, 3 hr at 100° (17). E, 2N (NH<sub>4</sub>)<sub>2</sub>S 3 hr at 100° (4, 7, 50). F, Na<sub>2</sub>HPO<sub>4</sub> 3 hr at 100° (28, 29, 50).

From No. 26 onwards in the case of the sodium hydroxide, ammonia and sodium carbonate tests the values quoted are the mean of three successive treatments.

R	I. N. C/	1	2	3	4	6	7	8	9	10	11	15	16
A		67.3	39.7	35.4	37.5	39.8	37.7	38.5	42.4	46.5	31.3	46.0	58.0
D		23.5	17.6		59.5	76.9	79.2	73.0	79.4	23.0	40.7	45.0	51.0

R	I. N. C/	26	29	30	31	32	33	34	35	36	37
A		129.2	92.2	97.4	79.8	94.6	104	78.6	157	114	121
B		21.4	20.0	20.7	18.0	20.6	17.5	15.3	45.6	30.2	37.1
C		3.2	4.5	2.7	3.0	2.9	2.6	2.4	7.2	4.9	5.6
D		30.7	30.1	27.7	24.7	26.0	27.7	36.0	200	87.8	121
E						1.0		1.2	1.1		
F, 0.5N							2.8	2.0	7.3		
F, 0.25N							1.6	1.2	5.3		

R	I. N. C/	38	39	40	41	42	43	44	45	46	47
A		95.7	98.0	93.6	118	79.8	82.3	79.1	81.0	96.4	91.2
B		17.7	21.4	18.8	30.7	15.5	18.6	21.8	13.7	28.1	32.8
D		29.2	48.5	36.0	51.1	32.3	29.1	26.0	25.3	141	132

TABLE 14

Action of Na<sub>2</sub>CO<sub>3</sub> and K<sub>2</sub>CO<sub>3</sub> solutions for 3 hr at 100° and of water and NaOH for 50 days at room temperature. Loss in wt., mg/100 cm<sup>2</sup> (14).

I. N.	Na <sub>2</sub> CO <sub>3</sub> g/l		K <sub>2</sub> CO <sub>3</sub> g/l	NaOH g/l				H <sub>2</sub> O†	
	13.2	132	172	10*	10†	100*	100†	a	b
C/22	46.4	75.8	48.1	3.9	4.6	5.2	5.7	6.6	6.0
C/23	49.5	83.3	52.8	4.5	5.1	6.3	6.2	16.5	12.6
C/24	26.3	45.2	21.2	5.1	6.4	6.0	6.7	23	22.5
C/25	24.8	41.2	20.0	5.5	5.0	6.6			

\* Successive treatments of same flask.

† I.e., alkali extracted by water in 50 days from (a) new flasks, (b) flasks pretreated with the 100 g/l NaOH for 100 days.

TABLE 15.—THE EFFECT OF BORIC OXIDE

Mg loss in wt. by 500 cm<sup>3</sup> flasks. Reagent: (1), N HCl boiling for; A, 0.5 hr; B, 2 hr; C, 0.1N HCl autoclave 3 hr. (2), 0.01N NaOH boiling for; D, 0.5 hr; E, 2 hr; F, 0.1N NaOH autoclave 3 hr at 120° (25, 26).

I. N.	R	A	B	C	D	E	F	I. N.	R	A	B	C	D	E	F
C/27					3.2	10.0	81	C/41		0.30	2.0	2.0	6.0	19.5	229
C/28		0.35	2.0	2.1	4.5	11.0	123	C/51		0.34	2.6	2.3	4.3	10.5	94
		* 0.33	2.5	2.2	4.5	10.7	108	C/52		0.33	2.5	2.2	4.5	10.7	108
C/50		0.50	3.1	2.5	2.5	9.0	81	C/53		0.31	2.0	2.0	6.0	19.1	200

\* Murano 1923, white badge.

TABLE 16

Per cent loss in weight in 1 hr by boiling water, 20.24% HCl, and 2N NaOH, respectively, acting on 20–30 mesh powdered glass (46, 52).

Wt. % composition: (75.8 - x)SiO<sub>2</sub> + xB<sub>2</sub>O<sub>3</sub> + 8.6CaO + 6.9Na<sub>2</sub>O + 7.9K<sub>2</sub>O + 0.66R<sub>2</sub>O<sub>3</sub>

x	H <sub>2</sub> O	HCl	NaOH	x	H <sub>2</sub> O	HCl	NaOH
0	0.060	0.056	1.50	12.5	0.085	1.45	2.32
0.5	0.060	0.056	1.45	15.0	0.105	7.40	2.70
1.0	0.060	0.056	1.45	20.0	0.170	29.8	3.95
2.5	0.060	0.056	1.46	25.0	0.485	47.2	5.65
5.0	0.060	0.060	1.55	30.0	1.150	54.80	8.00
7.5	0.062	0.090	1.75	35.0	2.175	59.4	13.5
10	0.068	0.300	2.00	40.0		62.6	25.5

TABLE 17.—ACTION OF NEUTRAL SALT SOLUTIONS  
mg/100 cm<sup>2</sup> loss in wt. in 3 hr at 100°

Na <sub>2</sub> SO <sub>4</sub> , 178 g/l (14)					5 % NH <sub>4</sub> Cl, mean, 3 successive treatments (4)									
I.N.C/	22	23	24	25	26	29	30*	31*	32	33	34*	36	37	
mg	1.8	3.1	1.6	2.3	0.25	0.28	0.28	0.23	0.40	0.28	0.16	0.29	0.39	

\* No loss on 3rd treatment.

TABLE 18.—THE INFLUENCE OF REAGENT CONCENTRATION  
mg/100 cm<sup>2</sup> loss in wt. (14, 15)

6 hr at 100°		Glass index No.			6 hr at 100°		Glass index No.		
Reagent	Equiv./l	C/8	14	15	Reagent	Equiv./l	C/8	14	15
H <sub>2</sub> SO <sub>4</sub>	0.001	0.2	1.1	1.7	HCl	0.001			1.5
	0.1	0.1	1.0	1.5		0.1	0.2	0.9	1.6
	1	0.2	1.2	1.7		1	0.3	1.1	1.9
	5	0.2	1.0			2	0.3		1.8
	10	0.3	0.9	1.7		4			1.7
	25	0.1	0.2	0.5	C <sub>2</sub> H <sub>4</sub> O <sub>2</sub>	0.1	0.2	0.8	1.6
(Sp. gr. = 1.84)		0.1	0.1	0.2	Acetic	1	0.2	0.8	1.7
					acid	5	0.1		1.4

TABLE 18.—THE INFLUENCE OF REAGENT CONCENTRATION.—  
(Continued)

mg/100 cm <sup>2</sup> loss in wt. (14, 15)									
6 hr at 100°		Glass index No.			6 hr at 100°		Glass index No.		
Reagent	Equiv./l	C/8	14	15	Reagent	Equiv./l	C/16	19	20
HNO <sub>3</sub>	0.1	0.2	1.2	1.7	HCl	1	1.2	0.3	1.4
	1	0.2	0.7	1.8		5	1.3		
	5	0.1	1.0	1.5	C <sub>2</sub> H <sub>4</sub> O <sub>2</sub>	1	0.9		
	10	0.4	1.2	1.5					
	16.5	0.2		1.0	H <sub>2</sub> SO <sub>4</sub>	1	1.2		
KOH g/l	14	140	210	280	420	490	Data for 6SiO <sub>2</sub> + (2 - x)R <sub>2</sub> O + xCaO in same paper (14)		
mg loss, 3 hr 100°	17.5	28.0	28.3	27.2	23.6	24.6			
I. N.	KOH g/l		NH <sub>4</sub> OH g/l (or wt. %)						
	140		490	4.3	43	10 %	25 %		
	3 hr at 100°			50 days at room temperature					
	C/22	21.7	20.8*		3.5		0.9		
	C/23	23.3	21.1*	3.6	3.5	3.2	1.0		
	C/24	26.9	21.6	3.4	3.5	3.6	1.0		
	C/25	28.5	24.1*	3.2	3.5	4.1	0.9		

\* Mean of 2 determinations.

TABLE 19.—INFLUENCE OF REPEATED ACTION AND TIME  
Continued action of H<sub>2</sub>O at 20° on glass No. C/21 (16)

Time of treatment	mmg (= 10 <sup>-6</sup> g) Na <sub>2</sub> O per 100 cm <sup>2</sup> dissolved from glass					
	1. In original condition	2. After 42 da in H <sub>2</sub> O vapor at 30°	3. After 42 da in moist CO <sub>2</sub> at 30°	4. After 12 mo in air of room	5. After 12 mo in outdoor air	4 followed by 3
1 min	36	65	59	48	66	109
1 day	63	62	10	50	45	13
2 days	19		7	17	18	6
3 days	14	17	6	15	15	7
5 days	14	14		12	12	6
7 days	11	9		9	8	
10 days	8	8		8	8	7

TABLE 20

mg/100 cm<sup>2</sup> loss in wt. by successive treatments (8)

No. of treat- ments	2 hr evap. H <sub>2</sub> O at 100°			1.5 hr evap. 20.24 % HCl			3 hr at 100°					
	C/31			26			2N NaOH			2N Na <sub>2</sub> CO <sub>3</sub>		
	C/31	33	35	26	31	35	31	33	35	32	33	35
1	0.6	1.2	12.2	7.0	2.1	3.75	68	86	160	25.7	26.2	85
2	0.7	1.65	8.7	9.1	2.9	2.25	75	97	143	21.7	26.1	121
3	0.75	1.8	5.6	8.8	2.4	1.5	68	97	124	20.0	30.1	135
4	0.9	1.7	5.2	9.0	2.1	1.35	83	86	131	22.6	27.0	135
5	0.2	0.08	2.4	8.8	2.0	0.9	75	111	132	22.8	28.3	157
6	0.3	0.3	2.3	10.2	2.2	1.05	78	99	120	24.8	29.8	137
7	1.05	1.5	3.4	8.5	2.0	1.3	77	97	130	22.6	25.3	130
8	0.9	1.4	2.6	9.6	2.2	1.1	74	117	137	23.2	27.3	181
9	0.15	0.9	2.8	9.9	2.3	1.2	67	110	121	22.6	25.7	154
10	0.08	0.8	4.4	10.9	2.2	1.3	75	100	153	21.8	27.7	163
11				10.4	2.2	1.2				21.9	24.5	138
12				8.8	2.0	0.9				21.8	25.2	145
13				11.0	1.75	0.7				21.6	27.3	133
14					2.25	0.6				20.3	23.5	149
15					2.0	0.9				20.4	23.7	141

TABLE 20.—(Continued)

mg/100 cm<sup>2</sup> loss in wt. by successive treatments (8)

20.24 % HCl evaporating for 1.5 hr										
No. of treatments...	16	17	18	19	20	21	22	23	24	25
Index No. C/31....	2.1	2.1	1.35	1.75	1.8	1.75	2.7	1.8	1.8	2.0
Index No. C/35....	1.1	1.05	0.3	0.15	0.3	0.3	0.9	0.45	0.6	0.45

TABLE 21.—THE INFLUENCE OF TEMPERATURE

Amount extracted per 100 cm<sup>2</sup> surface

Alkali extracted (14)						mg matter extracted (9)			
By H <sub>2</sub> O		Na <sub>2</sub> CO <sub>3</sub> , 132 g/l	K <sub>2</sub> CO <sub>3</sub> , 172 g/l	H <sub>2</sub> O for 24 hr 250 cm <sup>3</sup> flask					
Index No.	3 days room temp.	1 hr 80°	50 days room temp.	3 hr 100°	50 days room temp.	3 hr 100°	Index No.		
C/	10 <sup>-6</sup> g		10 <sup>-3</sup> g		C/	80°	90°	95°	100°
22	6.3	63	4.4	75.8	2.0	48.1	33	1.4	2.4
23	16.5	210	4.6	83.3	2.1	52.8	32	1.0	2.0
24	23	337	2.2	45.2	0.8	21.2	47	1.0	2.4
25	40	607	2.0	41.2	0.9	20.0	38	4.8	7.5

mg loss in wt. of 500 cm<sup>3</sup> flasks by 20.24 % HCl for 12 hr (9)

I. N. C/	90°	95°	99.9°	102°	104.8°
26	6.2	7.8	9.8	10.8	13.2
31	1.6	2.1	2.7	3.4	4.6
33	5.4	7.2	9.3	10.4	12.9

mg loss in wt. of 500 cm<sup>3</sup> flasks in 3 hr (5)

Index No. C/	By 2N NaOH					Index No. C/	By 2N Na <sub>2</sub> CO <sub>3</sub>				
	40°	60°	80°	90°	100°		40°	60°	80°	90°	100°
31	1.7	4.1	18.9	31.7	74.2	32		2.6	10.2	16.8	32.9
33	1.5	4.3	19.2	36.5	88.9	33		3.2	10.6	18.1	34.8
36			24.1	45.5	154	48	2.1	5.9	25.9	49.2	115

TABLE 22.—INFLUENCE OF CONCENTRATION, TIME AND TEMPERATURE

mg/100 cm<sup>2</sup> loss in wt. by action of commercially pure NaOH  
(C. P. NaOH somewhat less corrosive) (14)

NaOH g/l	Time	Temp. °C	Index No. C/			
			22	23	24	25
1	*3 hours	100			18.3	
10	50 days	18	3.9	4.5	5.1	5.5
10	*3 hours	100	27.6	32.8	35.2	34.5
100	50 days	18	5.2	6.3	6.1	6.6
100	*3 hours	100	54.0	58.3	60.6	62.9
450	50 days	18	1.8	1.7	2.0	3.7
	*3 hours	100	46.6	52.5	52.7	52.8

\* Not clearly stated in text, but assumed from reference from earlier page.



## OPTICAL GLASSES

TABLE 23

Hundredths-milligrams of iodococsin per 100 cm<sup>2</sup> surface (2, 45)

Glass index No.	Type	n <sub>D</sub>	Fractured surfaces					Polished surfaces			
			Fresh	7 da in moist air at 18°	Fractured under the soln.	Steamed 1 hr at 2 atm.	Grade	Fresh	7 da in moist air at 18°	Heated 4 hr 150°	Steamed 1 hr at 2 atm.
O/1	Fluor crown.....	1.4942	3	2	23		h <sup>1</sup>	2	2	3	
2	Borosil. crown....	1.5108	11	7	10	108	h <sup>2</sup>	2	3	4	63
3	Borosil. crown....	1.5135	8	3	18	106	h <sup>1</sup>	3	3	4	65
4	Borosil. crown....	1.5171	17	8	17	112	h <sup>2</sup>	2	2	3	72
5	Hard crown.....	1.5173	16	7	8	181	h <sup>2</sup>	4	6	9	155
6	Soft crown.....	1.5225	19	69	33		h <sup>5</sup>	8	26	23	
7	Light Ba crown....	1.5408	14	5	16	150	h <sup>1</sup>	3	2	3	108
8	Medium Ba crown..	1.5736	8	3	12	94	h <sup>1</sup>	4	4	3	94
9	Dense Ba crown....	1.6129	21	8	22	115	h <sup>2</sup>	4	3	3	84
10	Dense Ba crown....	1.6111	19	6	21	71	h <sup>2</sup>	3	3	3	47
11	Dense Ba crown....	1.6052	15	3	19	65	h <sup>1</sup>	4	2	4	45
12	Telescope flint....	1.5177	10	6	11	137	h <sup>2</sup>	5	2	4	122
13	Light Ba flint.....	1.5655	10	3	13	55	h <sup>1</sup>	4	4	3	37
14	Light Ba flint.....	1.5804	14	8	16	130	h <sup>2</sup>	5	3	4	126
15	Light Ba flint.....	1.5282	10	2	11	164	h <sup>1</sup>	4	2	3	140
16	Ba flint.....	1.6051	16	2	19	56	h <sup>1</sup>	3	2	3	55
17	Extra light flint...	1.5516	12	8	14	108	h <sup>2</sup>	3	4	4	99
18	Light flint.....	1.5741	8	4	10	106	h <sup>1</sup>	2	2	3	100
19	Light flint.....	1.5677	11	6	12	95	h <sup>2</sup>	3	2	2	89
20	Dense flint.....	1.6174	24	6	20	86	h <sup>2</sup>	3	2	2	85
21	Dense flint.....	1.6229	21	2	19	85	h <sup>1</sup>	3	2	3	80
22	Extra dense flint...	1.6521	26	1	20	69	h <sup>1</sup>	2	1	1	58
23	Borosil. crown....	1.5089	12	8			h <sup>2</sup>				
24	Hard crown.....	1.5186	19	9			h <sup>2</sup>				
25	Zinc crown.....	1.5160	11	5			h <sup>1</sup>				
26	Light Ba crown....	1.5040	22	3			h <sup>1</sup>				
27	Medium Ba crown..	1.5724	11	4			h <sup>1</sup>				
28	Dense Ba crown....	1.6087	24	9			h <sup>2</sup>				
29	Dense Ba crown....	1.6118	13	6			h <sup>2</sup>				
30	Dense Ba crown....	1.6129	14	5			h <sup>1</sup>				
31	Light Ba flint.....	1.5515	12	2			h <sup>1</sup>				
32	Dense Ba flint.....	1.6256	18	2			h <sup>1</sup>				
33	Dense Ba flint.....	1.6683	19	2			h <sup>1</sup>				
34	Extra light flint...	1.5280	11	6			h <sup>2</sup>				
35	Light flint.....	1.5789	17	2			h <sup>1</sup>				
36	Dense flint.....	1.6039	19	6			h <sup>2</sup>				
37	Dense flint.....	1.6221	20	4			h <sup>1</sup>				
38	Extra dense flint...	1.6475	20	2			h <sup>1</sup>				
39	Densest extra large flint.....	1.7072	14	1			h <sup>1</sup>				
40	Fluor crown.....	1.4933	4	2	4		h <sup>1</sup>	2	3	3	
41	Borosil. crown....	1.5100	17	8	17	107	h <sup>2</sup>	3	4	4	87
42	Silicate crown....	1.5144	28	20	34		h <sup>3</sup>	4	17	18	
43	Ordinary sil. crown.	1.5175	20	30	23		h <sup>4</sup>				
44	Soft sil. crown....	1.5151	41	58	48		h <sup>5</sup>	5	25	24	
45	Light Ba flint.....	1.5646	15	5	16	102	h <sup>1</sup>	3	2	2	86
46	Ordinary light flint.	1.5800	14	7	16	104	h <sup>2</sup>	3	2	3	81
47	Heavy flint.....	1.6190	23	2	19	80	h <sup>1</sup>	2	2	2	71

TABLE 24.—DURABILITY BY AUTOCLAVE TREATMENT

Dimming test (appearance after weathering polished surface in air saturated with water vapor at 80° for 30 hr) and moisture retained by powdered glass. Grading by apparent effect of autoclave treatment: Grade 1 = least apparent effect. Grade 5 = greatest apparent effect. Dimming test: Three grades, 1, 2, 3. Symbols 1+ and 2- = rather worse than 1 and rather better than 2 resp. (2, 13, 45).

Glass ind. No.	Water for 4 hr at 4 atm.			Grade by dimming test	mg H <sub>2</sub> O retained per 100 g glass powder, 90-100 mesh	
	Loss in wt. mg/100 cm <sup>2</sup>	Iodo-eosin value of water extract	Grade by appearance		Dried in vacuo	Heated to 120°C
O/1	127	182	5			
2	16.6	25.8	3	2	33	0
3	14.8	43.8	1			
4	10.9	41.3	1			
5	16.9	38.6	1	2—	135	87
6		1875	5	3—	230	151
7	21.7	38.0	3	1	9	0
8	10.5	31.4	3	1+	26	7
9	14.0	31.0	1	1+	26	7
10	11.5	19.7	4	2—	27	13
11	9.8	30.8	4			
12	8.6	21.9	4	2—	71	36
13	9.2	20.9	4	1+	28	12
14	8.5	18.9	4	2—	53	17
15	5.8	30.0	2			
16	6.1	11.5	3			
17	2.7	15.5	2			
18	3.7	10.4	2			
19	3.2	8.5	1	1	43	27
20	4.7	4.2	2	1+	28	16
21	3.2	3.4	2			
22	4.8	6.3	2			
23	27.2	73.2	2			
24	17.3	61.7	2			
25	13.7	31.7	4			
26	18.8	48.0	4			
27	11.0	31.7	3			
28	8.4	24.9	3			
29	9.2	20.7	3			
30	9.0	28.9	1			
31	5.3	18.5	2			
32	2.6	3.5	3			
33	2.8	4.3	3			
34	3.5	19.6	4			
35	2.4	7.7	1			
36	3.8	6.1	2			
37	2.7	2.7	1			
38	4.0	5.2	2			
39	1.3	1.6	1			
40	513	545	5			
41	21.6	63.6	3			
42	18.2	68.5	4			
43	12.9	63.4	4			
45	10.9	25.8	4			
46	3.3	9.4	3			
47	4.5	9.1	3			

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## VITREOUS ENAMELS FOR METALS

### RALPH R. DANIELSON AND H. G. WOLFRAM

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Strength.  
Hardness.  
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## MATIÈRES

Compositions.  
Densité.  
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## INHALTSVERZEICHNIS

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Dichte.  
Festigkeit.  
Härte.  
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## COMPOSITIONS

## 1. MOLECULAR COMPOSITIONS

Component	Na <sub>2</sub> O	K <sub>2</sub> O	CaO	ZnO
Type				
Jewelry (28).....	0.3 -0.6	KNaO	0	0
Cast Fe (3).....	0.54	0.16	0.10	0.05
Cast Fe (15).....	0.70-0.74	0.06-0.11	0-0.19	0-0.2

Component	PbO	Al <sub>2</sub> O <sub>3</sub>	As <sub>2</sub> O <sub>3</sub>	Sb <sub>2</sub> O <sub>3</sub>
Type				
Jewelry (28).....	0.4-0.7	0	0.05-0.15	0
Cast Fe (3).....	0.15	0.16	F	0.075
Cast Fe (15).....	0	0.12-0.15	0.6 -0.86	0-0.13

Component	B <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub>	SnO <sub>2</sub>	P <sub>2</sub> O <sub>5</sub>
Type				
Jewelry (28).....	0-0.2	1.3 -1.8	0	0
Cast Fe (3).....	0.20	1.80	0	0
Cast Fe (15).....	0.68-1.14	0.64-0.77	0-0.34	0-0.43

## 2. WEIGHT PER CENT

A = Jewelry enamels.  
B = Single coat gray ware enamels.  
C = Dry process white cover enamels for cast iron.  
D = Single coat white enamel. Wet process for cast iron.  
E = White cover enamels. Wet process for cast iron.  
F = White cover enamels for sheet iron and steel.  
G = Ground coats for sheet iron and steel.

Enamel	Component	Quartz	Feldspar	Borax	H <sub>3</sub> BO <sub>3</sub>	Na <sub>2</sub> CO <sub>3</sub>	NaNO <sub>3</sub>	K <sub>2</sub> CO <sub>3</sub>	KNO <sub>3</sub>	Cryolite	CaF <sub>2</sub>	Lit.
A		14.4			19.2		9.9		23.2			(30)
A		31.2	1.2			1.7	2.4	2.1	2.9			(8)
B			50.2	30.5		3.1	3.1			3.7	4.2	(1)
B		10.0	40.0	30.5		6.5	5.5				1.5	(6)

## 2. WEIGHT PER CENT.—(Continued)

Enamel	Component	Quartz	Feldspar	Borax	H <sub>3</sub> BO <sub>3</sub>	Na <sub>2</sub> CO <sub>3</sub>	NaNO <sub>3</sub>	BaCO <sub>3</sub>	KNO <sub>3</sub>	Cryolite	CaF <sub>2</sub>	Lit.
C			33.1	18.7		2.6	2.6			2.6	4.4	(26)
C			33.4	19.5	17.9		2.4	4.4		9.8		(26)
D		12.8	18.9	25.6						9.4	2.7	(24)
D			36.0	31.8		5.5	3.7			3.2		(9)
E		10.2	32.3	20.8		3.3	3.3			4.3	4.7	(9)
F		17.0	31.0	27.0		3.5	3.5			12.0	5.0	(6)
F		22.0	31.0	21.0		3.5	3.5	CaCO <sub>3</sub>		17.0		(6)
G		20.5	27.0	30.0		9.8	5.0				6.0	(6)
G		21.0	26.0	34.6		7.4	4.0	2.2			3.5	(19)
G		29.0	22.0	30.0		5.0	4.6				6.0	(6)

Enamel	Component	Bone ash	Pb <sub>3</sub> O <sub>4</sub>	ZnO	SnO <sub>2</sub>	As <sub>2</sub> O <sub>3</sub>	Sb <sub>2</sub> O <sub>3</sub>	MnO <sub>2</sub>	Ni <sub>2</sub> O <sub>3</sub>	Co <sub>2</sub> O <sub>3</sub>	Lit.
A			33.3								(30)
A			53.8			4.7					(8)
B		3.1					2.1				(1)
B		4.5					1.5				(6)
C			14.6	9.1	7.9						(26)
C				10.2	6.8						(26)
D			30.6								(24)
D			18.2				1.6				(9)
E			14.0	5.1							(9)
F							1.0				(6)
F							2.0				(6)
G								1.2		0.5	(6)
G								0.26	0.26	0.26	(19)
G								2.0	1.9	0.4	(6)



## SPECIFIC GRAVITY

Ground coat for sheet steel 2.54. White cover enamel for sheet steel 2.66. High lead-tin oxide enamel for cast iron 2.93. Leadless antimony enamel for cast iron 3.32. High lead oxide enamel for jewelry 3.79 (31).

## STRENGTH

## Ultimate Compressive Strength (Def. 4)

Commercial ground coat for sheet steel, 95 500 lb./in.<sup>2</sup>. Commercial white cover for sheet steel, 91 740 lb./in.<sup>2</sup>. Cylindrical test pieces ½ in. diam. × 1 in. long (11).

## Cross Bending Strength

See (12, 20).

## Impact Resistance

See (11, 17, 29).

## HARDNESS

See (2).

## THERMAL EXPANSION OF VITREOUS ENAMELS

The coefficient of cubical expansion,  $\frac{10^7 dV}{V dt}$ , can be approximately calculated from the wt. % composition of the melted enamel and the moduli given below.

## MODULI

AlF <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	As <sub>2</sub> O <sub>5</sub>	BaO	B <sub>2</sub> O <sub>3</sub>	BeO	CaO	CaF <sub>2</sub>	CeO <sub>2</sub>	CoO	Cr <sub>2</sub> O <sub>3</sub>	Cryo-lite	CuO	FeO
4.4	5.0*	2.0	3.0	0.1*	4.7	4.9†	2.5	4.2	4.4	5.1	7.4	2.2	4.0
K <sub>2</sub> O	MgO	MnO	NaF	Na <sub>2</sub> O	NiO <sub>2</sub>	PbO	Sb <sub>2</sub> O <sub>5</sub>	SiO <sub>2</sub>	SnO <sub>2</sub>	ThO <sub>2</sub>	TiO <sub>2</sub>	ZrO <sub>2</sub>	ZnO
8.5*	0.1*			10*			0.8*						
	1.35†	2.2	7.4	13†	4.0	4.2	3.6	0.15†	2.0	6.3	4.1	2.1	1.8

\* Values from Winkelman and Schott (32).

† Values from English and Turner (13).

All others from Mayer and Havas (18).

The calculation is illustrated in the following example and in the table of Expansion of Enamels.

Composition	Wt.	Moduli
Silica.....	25.30 ×	0.8 = 20.2
Alumina.....	7.20 ×	5.0 = 36.0
Potassium oxide.....	6.60 ×	8.5 = 56.1
Sodium oxide.....	8.94 ×	10.0 = 89.4
Boric oxide.....	12.77 ×	0.1 = 1.3
Barium oxide.....	6.21 ×	3.0 = 18.6
Zinc oxide.....	14.00 ×	1.8 = 25.2
Calcium oxide.....	1.68 ×	5.0 = 8.4
Calcium fluoride.....	7.30 ×	2.5 = 18.3
Antimony oxide.....	10.00 ×	3.6 = 36.0
	100.00	309.5

The calc. cubical coefficient of expansion for this enamel is therefore  $309.5 \times 10^{-7}$  per °C.

Danielson and Souder (10) have shown, however, that values so calculated are only approximate. The following are typical:

Types of enamel	Coeff. of linear expansion × 10 <sup>6</sup> , Observed values				$\frac{10^6 \Delta l}{l \Delta t}$ Calculated values
	20° to 200°C	20° to 400°C	20° to 450°C	20° to 500°C	
Single coat gray ware ..	9.8	11.6		13.4	11.0
Ground coat for sheet steel.....	9.4	10.3	11.5		

The determinations made by Mayer and Havas were over the range 0–100°C while those made by Danielson and Souder were carried to the softening points of the enamels, *i.e.*, about 450° to 500°C. It will be noted that the coefficient rapidly increases with increase in temperature as shown by Fig. 1 (10).

The results of these various studies indicate that the factors given by Mayer and Havas place the oxides in approximately their correct order as regards their relative effect on the expansivity of enamels and may thus serve as a valuable guide in the technical control of enamel mixtures.

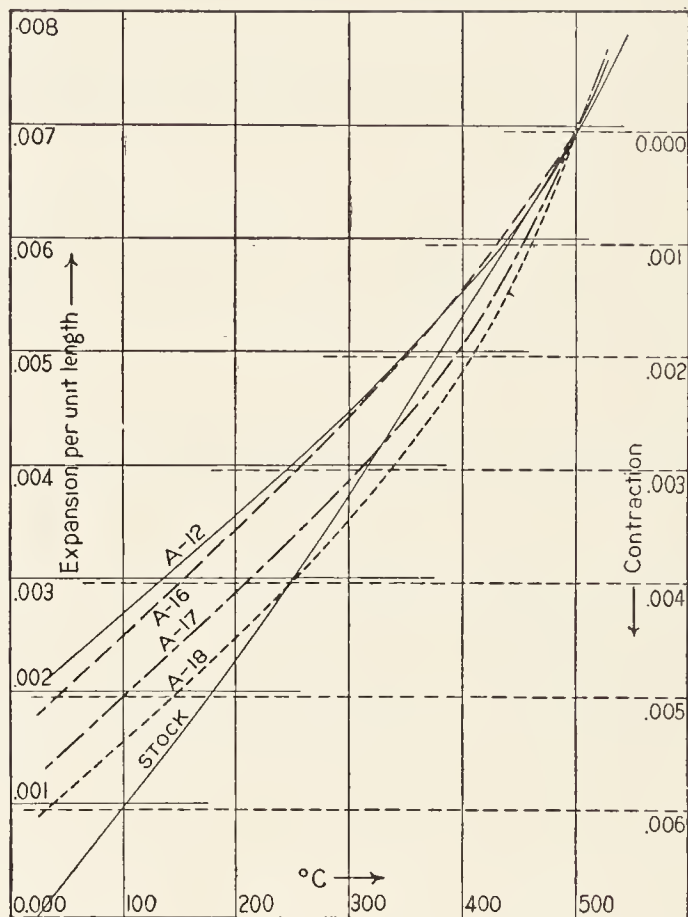


FIG. 1.—Expansion of some typical gray ware enamels and enameling steel.

From the observations of the various investigators it may generally be assumed that the average coefficients of expansion of commercial enamels and enameling metals will be within the following limits:

Type of enamel	$\frac{10^7 dV}{V dt}$
Ground coat for sheet steel.....	260 to 320
White cover enamel for sheet steel.....	320 to 400
White enamel for cast iron.....	290 to 330
White enamel for jewelry.....	300 to 350
Cast iron.....	310
Sheet iron and steel.....	381 to 438

For table of expansion of various enamels *v.* p. 116.

## HEAT TRANSFER BY ENAMELED METALS

Observations on a large number of commercial steel enameled units led to the following over-all coefficients of heat transfer under the conditions named (22).

Operating conditions	Over-all coefficient joule m <sup>-2</sup> hr <sup>-1</sup> (°C)
Steam, to cold water.....	1674 to 2929
Hot water, to cold water....	1464
Steam, to boiling water.....	2929
Steam, to thick fruit product.....	669
Hot water, to cold water or brine .....	837 to 2510
Hot oil, to cold oil.....	271 to 586
Hot oil, to boiling water.....	628 to 837
Steam, to water in tubular heaters.....	2092 to 3347
Condensing steam to water in tubular condenser jacket.....	2929

Velocities of liquids over heating surfaces as affected by agitation, differences in mobility, and specific heat were involved in the above experiments.

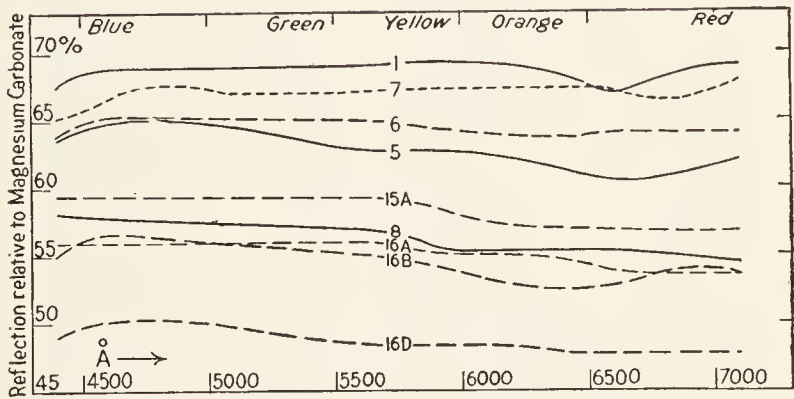


FIG. 2.—Opacifiers for enamels. No. 1. Tin oxide, 7 %. No. 7. Sodium antimonate, 11 %. No. 6. Sodium antimonate, 9 %. No. 5. Sodium antimonate, 7 %. No. 15A. Feldspar calcined, 9 %. No. 16A. Zinc aluminate calcined, 9 %. No. 8. Zinc aluminate calcined, 7 %. No. 16B. Zinc aluminate, 9 %. No. 16D. Zinc aluminate, 9 %.

The data on enameled cast-iron units are more limited. Over-all coefficients of heat transfer are given ranging from 1038 to 1464.

The thickness of the enamel coating rather than the thickness of the metal, seems to be the determining factor in the over-all coefficient.

THERMAL EMISSIVITY OF WHITE VITREOUS ENAMELED SURFACES

Very nearly the same as that of white-lead paint (4).

REFLECTIVITY OF SHEET STEEL ENAMELS

A typical white tin oxide enamel for sheet steel has an average reflectivity of 69%, relative to magnesium carbonate (7).

The same frit with other opacifying agents replacing tin oxide has reflectivities varying between 48 and 66% as shown in Figs. 2 and 3 (7).

See (27) for the effect of fineness of grinding on the opacity of enamels.

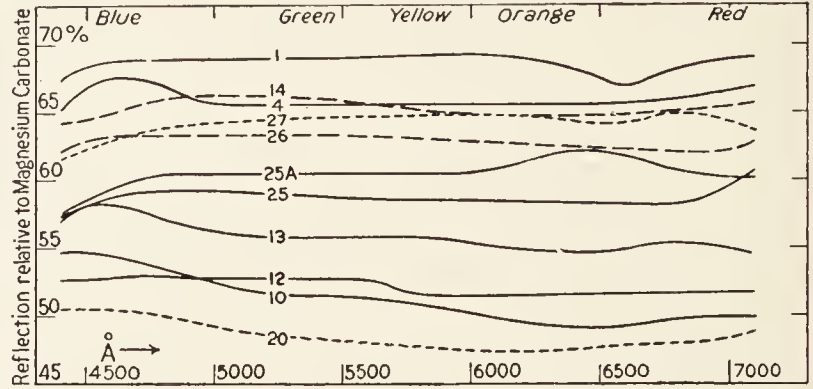


FIG. 3.—Opacifiers for enamels. No. 1. Tin oxide, 7 %. No. 4. Zirconium oxide, 7 %. No. 14. Zirconium oxide, 9 %. No. 10. Zirconium product, 7 %. No. 13. Commercial substitute, 7 %. No. 26. Zirconium silicate B, 9 %. No. 25. Zirconium silicate B, 7 %. No. 25A. Zirconium silicate B calcined, 7 %. No. 12. Zirconium silicate A, 7 %. No. 20. Zirconium silicate A, 11 %. No. 27. Zirconium silicate B, 11 %.

EXPANSION OF ENAMELS OF VARIOUS COMPOSITIONS (18)

Percentage composition of enamels

Type of enamel. . . .	SiO <sub>2</sub>	B <sub>2</sub> O <sub>3</sub>	Cryolite		CaF <sub>2</sub>	CoO	MnO	Al <sub>2</sub> O <sub>3</sub>	CaO	K <sub>2</sub> O	Na <sub>2</sub> O	10 <sup>6</sup> dV / V dt	
			AlF <sub>3</sub>	NaF								Obs.	Calc.
Ground coat. . . . .	51.00	15.79			5.44	0.25	0.71	7.86	1.51	2.60	14.84	28.8	27.6
	64.86	9.46			3.67	0.21	0.51	6.45	1.01	1.71	12.12	24.5	23.7
	54.69	12.47			4.68	0.31	0.45	8.83	1.26	2.54	14.77	28.9	27.9
Cover. . . . .	55.91	6.96	3.95	6.03	1.73			10.30	0.54	1.73	12.85	32.7	32.1
	51.00	6.80	6.29	9.62				8.85	1.77	2.28	13.39	35.8	36.1
	51.40	8.31	3.87	5.77	2.14			11.58	1.30	0.97	14.66	34.6	33.8
	48.08	8.98	6.38	9.75				9.36	0.54	1.67	15.24	37.2	37.5
Cover, with various oxides	54.81	6.82	3.87	5.91	1.70		SnO <sub>2</sub>						
	53.76	6.69	3.80	5.80	1.66		1.96	10.10	0.53	1.70	12.60	31.8	31.8
							3.85	9.90	0.52	1.66	12.36	30.9	31.6
							TiO <sub>2</sub>						
	54.81	6.82	3.87	5.91	1.70		1.96	10.10	0.53	1.70	12.60	32.7	32.2
	53.76	6.69	3.80	5.80	1.66		3.85	9.90	0.52	1.66	12.36	31.1	32.4
							ZrO <sub>2</sub>						
	54.81	6.82	3.87	5.91	1.70		1.96	10.10	0.53	1.70	12.60	31.2	31.8
	53.76	6.69	3.80	5.80	1.66		3.85	9.90	0.52	1.66	12.36	30.1	31.6
Dry process. . . . .	33.92	5.01	As <sub>2</sub> O <sub>3</sub>	PbO	ZnO			0.22	0.41	0.75	6.51	30.1	30.7
			5.23	44.61	3.34								



## ACID RESISTANCE OF VITREOUS ENAMELS

See (20, 16, 21, 5, 23, 14, 11, 29) for sheet steel enamels and (25) for cast iron enamels.

## LITERATURE

(For a key to the periodicals see end of volume)

(1) Arnold, 38, 5: 86; 22. (2) Blumenthal, 38, 4: 900; 21. (3) Brown, 81, 14: 470; 12. (4) Coblenz and Hughes, 32, No. 254; 24. (5) Collins, 45, 11: 757; 19. (6) Danielson, 38, 3: 961; 20. (7) Danielson and Frehafer, 38, 6: 634; 23. (8) Danielson and Reinecker, 38, 4: 827; 21. (9) Danielson and Reinecker, 32, No. 246; 23.

(10) Danielson and Souder, 38, 4: 631; 21. (11) Danielson and Sweely, 38, 6: 1011; 23. (12) Danielson and Lindemann, 38, 8: 795; 25. (13) English and Turner, 105, 4: 115; 20. 5: 121; 21. 5: 183; 21. (14) Frost, 38, 1: 422; 18. (15) Kraze, 100, 49: 33; 14. (16) Landrum, 81, 13: 494; 11. (17) Landrum, 81, 14: 489; 12. (18) Mayer and Havas, 100, 44: 188, 207, 220; 11. (19) Menzel, 103, 22: 423; 14. (20) Orton, 81, 11: 320; 09. (21) Poste, 81, 17: 137; 15. 18: 762; 16. 38, 2: 32; 19. 3: 560; 20. (22) Poste, 45, 16: 469; 24. (23) Shaw, 81, 12: 463; 10. (24) Shaw, Notes submitted to Data Committee, American Ceramic Society. (25) Staley, 38, 4: 703; 21. (26) Staley, 32, No. 142: 85; 19. (27) Sweely, 38, 5: 855; 22. (28) Sweely, 38, 4: 350; 21. (29) Wolfram, 38, 7: 1; 24. (30) Wolfram and Harrison, 38, 7: 857; 24. (31) U. S. Bureau of Standards, O. (32) Winkelmann and Schott, 8, 51: 735; 94.

## STRUCTURAL CEMENTS, LIMES AND PLASTERS

P. H. BATES AND W. E. EMLEY

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## HYDRAULIC CEMENTS

P. H. BATES

Hydraulic cements have the property of hardening under water and are usually made by burning argillaceous limestones or mixtures of argillaceous and calcareous materials. They include: portland, rosendale, natural, grappier, Eisenportland, Erzportland, Hochofen, trass, tufa, pozzuolana, etc., and hydraulic limes.

The definition and classification of cements is largely a matter of usage, which varies from nation to nation. In the U. S. there is a well-recognized standard for portland cement alone (A. S. T. M., C9-21).

A very infrequently used standard for natural cement differentiates this from portland cement only by its not requiring grinding before calcination, and giving different numerical values for the other properties (A. S. T. M., C10-09).

Rosendale, grappier, and hydraulic limes are natural cements in that the raw material is not ground before calcination. The other classes of cement mentioned above are mixtures of portland cement with various amounts of different slags of natural or of artificial origin. Their use is not very extensive and in general is confined to a few countries.

In France one standard covers the several varieties of hydraulic limes and cements (3).

"Hydraulic limes and cements will be called quick-, medium-, slow-, or extremely slow-setting according as their time of initial set is less than 5 min, 5 to 30 min, 30 min to 6 hr or more than 6 hr respectively.

"Until the time when compression test results can be generalized, the classification by strength shall be made as follows according to minimum strength in tension at 7 and 28 days."

Designation (package to show this designation)	Minimum tensile strength			
	kg cm <sup>-2</sup>		lb. in. <sup>-2</sup>	
	7 da	28 da	7 da	28 da
1/3 kg	1	3	14.2	42.6
3/5 kg	3	5	42.6	71.0
6/10 kg	6	10	85.0	142.0
10/15 kg	10	15	142.0	213.0
15/20 kg	15	20	213.0	284.0
20/25 kg	20	25	284.0	355.0

The chemical composition of all cements, even of the same class, varies widely. The following table, taken from the file of the U. S. Bureau of Standards, gives the composition of some portland cements of the U. S., wt. %:

SiO <sub>2</sub> .....	22.25	25.02	20.75	22.66	20.37	23.40	19.03	19.82	20.80
Al <sub>2</sub> O <sub>3</sub> ....	6.63	6.08	7.79	5.58	3.64	6.97	8.75	7.62	6.94
Fe <sub>2</sub> O <sub>3</sub> ....	2.26	.49	2.40	4.51	8.97	2.68	4.75	2.10	3.84
CaO.....	63.84	62.89	60.48	62.22	61.42	60.87	62.81	62.04	64.12
MgO.....	2.41	1.11	3.28	.62	.82	1.13	1.33	3.90	1.02
SO <sub>3</sub> .....	1.07	1.75	1.76	1.05	1.19	1.41	1.37	1.43	1.30
Na <sub>2</sub> O....	.21		.16	.17	1.54		.07	.24	
K <sub>2</sub> O.....	.32		.80	.19	.24		.16	.26	
Ig. loss...	1.14	2.03	2.76	2.86	2.07	2.78	1.56	2.72	1.26

In the following table are given the analyses of some other cements:

	Natural cements <sup>(10)</sup>			Hydraulic lime (3)	Erzportland <sup>(10)</sup>	Slag (CaS, 2.7 %) <sup>(10)</sup>	White (10)
SiO <sub>2</sub> . . . . .	20.85	24.07	23.81	22.89	20.37	30.19	22.66
Al <sub>2</sub> O <sub>3</sub> . . . . .	6.04	11.69	8.01	} 2.15 {	3.64	11.08	8.61
Fe <sub>2</sub> O <sub>3</sub> . . . . .	1.40	.35	4.18		8.97	1.64	.55
CaO . . . . .	34.83	47.08	32.00	64.85	61.42	46.16	62.46
MgO . . . . .	22.25	1.51	18.45	1.47	.82	2.17	1.10
Na <sub>2</sub> O . . . . .	.14	.25	.26		1.54	.29	.40
K <sub>2</sub> O . . . . .	1.60	.91	.44		.24	.64	.53
SO <sub>3</sub> . . . . .	2.11	.10	2.53	.61	1.19	1.10	1.64
Ig. loss . . . . .	11.12	1.79	8.26	8.03	2.07	4.00	2.06

## PORTLAND CEMENT

P. H. BATES

In view of the relatively very small amounts of cements used other than portland, and especially in view of the lack of any critical data on these other types of cements, this section will deal only with portland cements and products made therefrom.

Portland cement is a heterogeneous mixture of several compounds of silica, alumina and lime (being mostly 3CaO.SiO<sub>2</sub>,

$2\text{CaO} \cdot \text{SiO}_2$ ,  $3\text{CaO} \cdot \text{Al}_2\text{O}_3$ , glass and uncombined lime), produced by heating to incipient fusion finely ground mixtures of limestone, marl, or other calcareous compounds with certain argillaceous materials as clay, shale, slag, etc. The cement contains, in addition to the above, compounds or solid solutions of iron, magnesium, sodium, potassium, titanium, etc. The compounds present do not occur in fixed or definite quantities and as a consequence the properties of portland cement vary widely. Furthermore, as it is not stable towards water, moisture, or carbon dioxide in the presence of moisture, its properties are constantly changing (2).

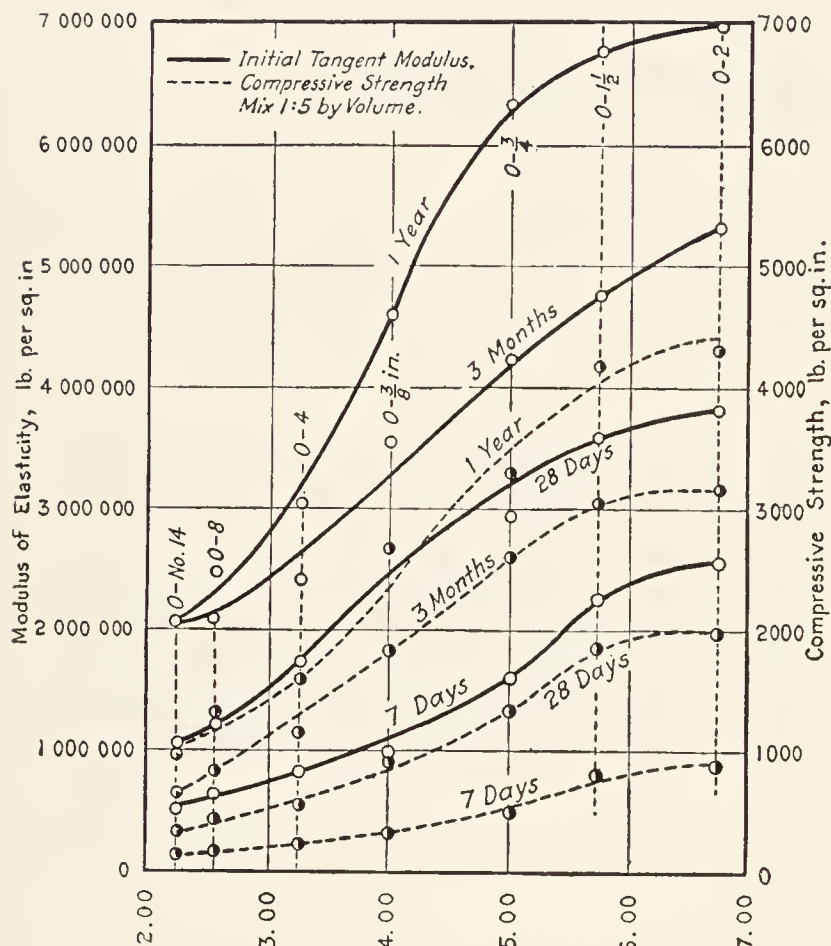


FIG. 1.—Effect of size of aggregate on modulus of elasticity. Compression tests of 6 by 12-in. cylinders. Sand and pebble aggregate. Relative consistency 1.10. Each value is the average of 24 tests from 6 times of mixing.

On mixing portland cement with water certain hydration reactions take place. The character and degree of these reactions depend upon the amount of water used and the presence of dissolved salts. The character and the degree of the reaction determine also the physical properties of the resulting material.

In view of the lack of the use of cement in the neat form (cement and water without the presence of any aggregate, either fine or coarse) no data will be presented referring to the properties when so used. All data will refer to concrete—large particles bonded with cement, or mortar—fine particles, all passing the  $\frac{3}{8}$  inch sieve, bonded with cement.

#### Strength of Concrete

The following equations have been suggested for calculating the compressive strength (Def. 4). Feret (22) states that if values of the expression

$$\left( \frac{V_c}{1 - V_s - V_A} \right)^2$$

[where  $V_c$  = absolute volume of cement in unit volume of mortar,

$V_s$  = abs. vol. of sand in unit vol. of mortar,

and  $V_A$  = abs. vol. of large aggregate in unit vol. of mortar]

be graphed against the compressive strength (Def. 4) of any concrete made of any aggregate of the same consistency, aged under the same condition and for the same period, the points so obtained will lie close to a straight line passing through the origin.

According to Abrams (1) the compressive strength,  $S$ , is expressed by the equation  $S = A/B^x$

where  $x$  = the  $\frac{\text{water}}{\text{cement}}$  vol. ratio in the mixture, and  $A$  and  $B$

are constants depending upon the quality of cement, age of concrete, curing conditions, etc.

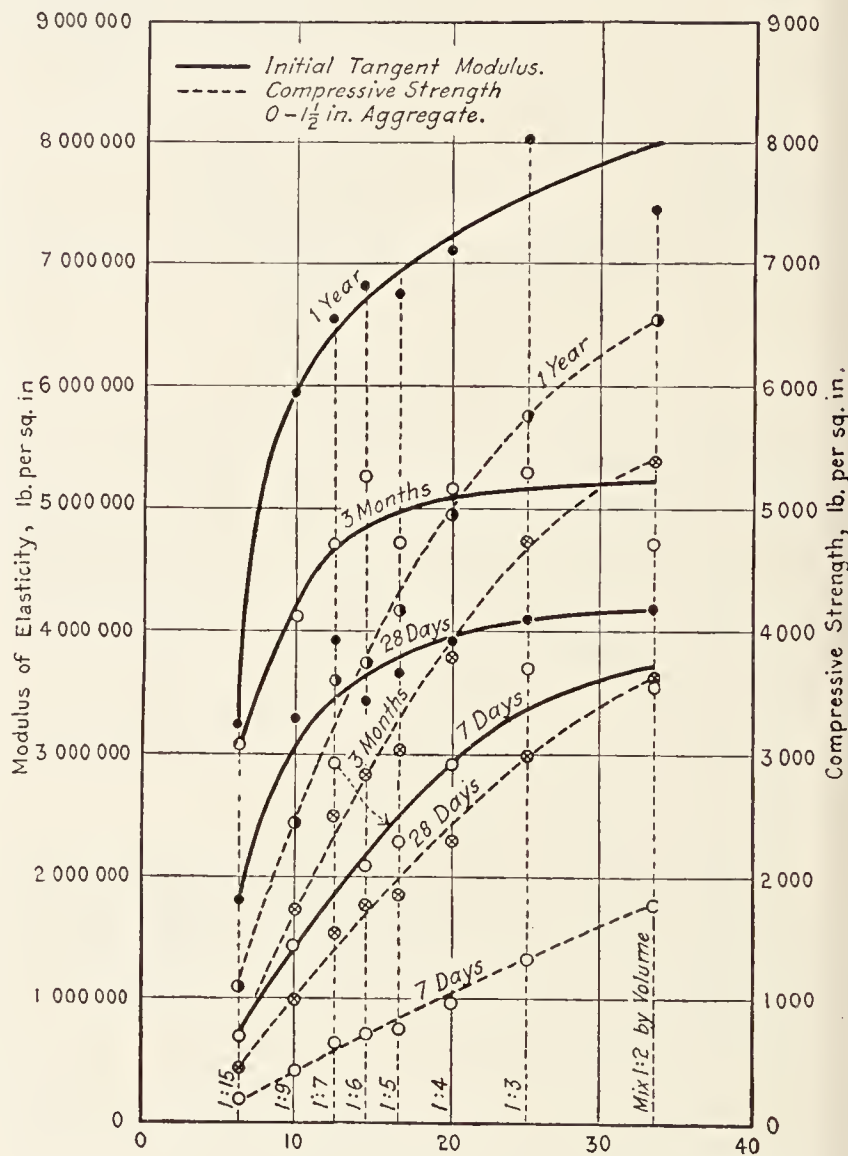


FIG. 2.—Effect of amount of cement on modulus of elasticity. Compression tests of 6 by 12-in. cylinders. Sand and pebble aggregate; graded 0-1 1/2 in. Relative consistency 1.10. Each value is the average of 24 tests from 6 times of mixing.

Talbot (40) finds  $S = 32\,000 \left( \frac{C}{V + C} \right)^{2.5}$  lb./in.<sup>2</sup>,

where  $C$  = vol. of cement in unit vol. mixture

and  $V$  = voids (air and water) in unit vol. mixture, when the "basic water" content is used. The "basic water" content is the amount of water per unit volume of the mortar that gives the minimum voids. The relation between strength and relative water content is not a straight line function. The strength of the concrete having a water content of 1.5 times that of the basic content would be reduced about one-third.



### Modulus of Elasticity

Walker (42) gives  $E = CS^m$

where  $E$  = modulus of elasticity,

$C$  and  $m$  = constants depending upon the conditions of test,  
and  $S$  = the compressive strength.

"Four different measures of modulus of elasticity of concrete are in more or less common use, as follows:

$E_i$  = the initial tangent modulus;

$E_t$  = tangent modulus at some load;

$E_s$  = secant modulus at some load;

$E_d$  = load modulus between two loads.

The initial tangent modulus for usual concrete mixtures may be represented by the equation  $E_i = 33\,000\,S^{5/8}$ . For the tangent modulus at 25% of the compressive strength the equation becomes  $E_t = 66\,000\,S^{1/2}$ ."

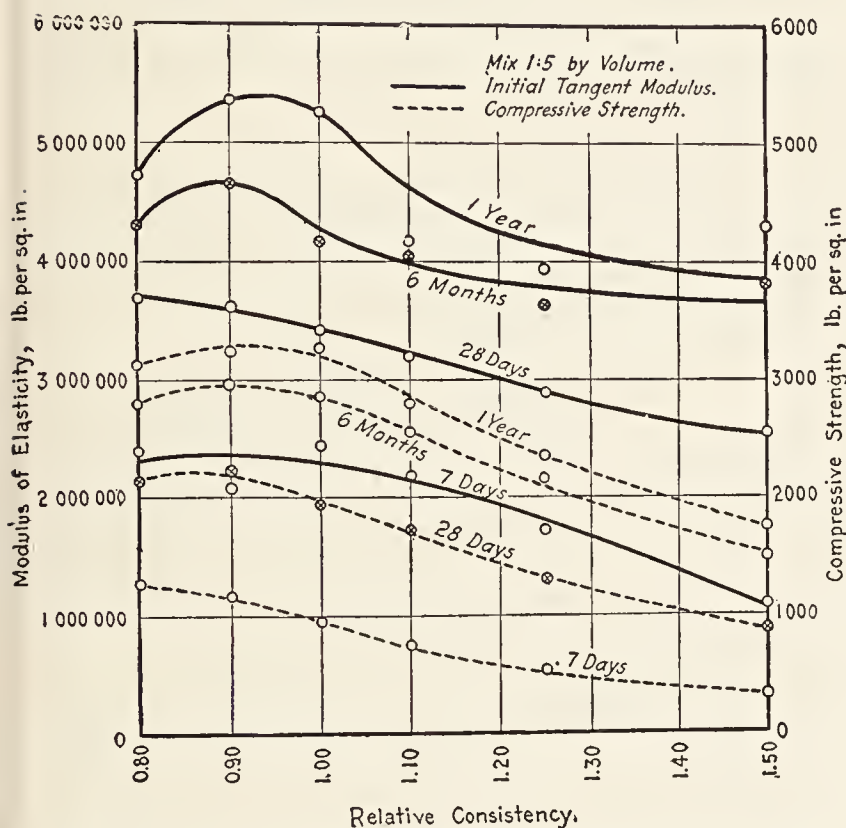


FIG. 3.—Effect of consistency of concrete on modulus of elasticity. Compression tests of 6 by 12-in. cylinders. Each value is the average of 15 tests from 3 sizes of sand and pebble aggregate.

Figures 1-4 illustrate the effect of the several variables mentioned above on the initial tangent modulus. In these graphs certain of the terms used have the same significance as indicated in the tables under "Strengths."

### Poisson's Ratio (Def. 9)

Recorded values range from 0.08 to 0.18 (27, 39, 50).

### Bulk Density

Varies from 0.68 to 0.90, according to grading and size of particles and is not affected by aging or slight changes in mixing temperature.

### Thermal Expansion

Norton (34) found the following values for a "1:2:5 stone concrete." The concrete was permanently deformed by the heat treatment and did not return to its original length. The length

on cooling was 75% of the maximum length obtained during heating.

Temperature range	$\frac{10^6 \Delta l}{l \Delta t}$
72°–360°F	4.5 to 6.0
72°–750°F	5.0 to 6.0
72°–1190°F	4.0 to 5.0
72°–1600°F	3.5 to 4.2

### SPECIFIC HEAT (34)

Temperature range	g-cal g <sup>-1</sup> deg. <sup>-1</sup> C		
	1:2:5 stone	1:2:4 stone	1:2:4 cinder
72°–312°F	0.156	0.154	
72°–372°F	.192	.190	0.180
72°–1172°F	.201	.210	.206
72°–1472°F	.219	.214	.218

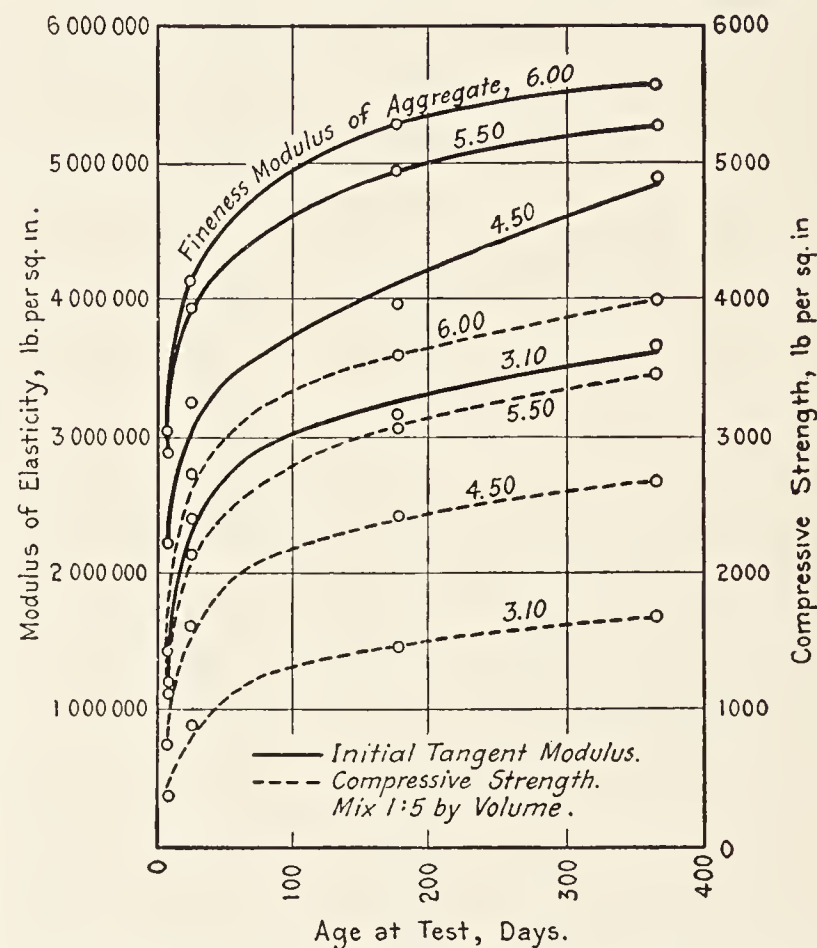


FIG. 4.—Effect of age of concrete on modulus of elasticity. Compression tests of 6 by 12-in. cylinders. Mix 1:5 by volume. Each value is the average of 30 to 35 tests from 6 or 7 consistencies.

### Thermal Conductivity

$$1 \text{ g-cal cm}^{-2} \text{ sec}^{-1} (\text{°C, cm}^{-1})^{-1} = 1.24 \text{ BTU ft.}^{-2} \text{ sec}^{-1} (\text{°F, in.}^{-1})^{-1}$$

Upper temp., °C	Norton (34)	$k$ g-cal unit
	Mix	
35	stone 1-2-5*	0.00216
50	stone 1-2-4*	0.00113
50	cinder 1-2-4	0.00081
200	stone 1-2-4	0.0021
400	stone 1-2-4	0.0022
500	stone 1-2-4	0.0023
1000	stone 1-2-4	0.0027
1100	stone 1-2-4	0.0029

\* Not tamped.

Mixture by volumes		50°C to 100°C 120°F to 212°F	100°C to 200°C 212°F to 390°F	200°C to 300°C 390°F to 570°F
Cement: aggre- gate	Cement: sand: gravel	g-cal cm <sup>-2</sup> sec <sup>-1</sup> (°C, cm <sup>-1</sup> ) <sup>-1</sup>		
		k	k	k
"Neat"		0.00140	0.00163	0.00140
1-2	1-1.2-1.1	0.00326	0.00344	0.00318
1-3	1-1.9-1.7	0.00335	0.00379	0.00318
1-4	1-2.4-2.3	0.00413	0.00352	0.00328
1-5	1-3.1-3.0	0.00327	0.00323	0.00334
1-7	1-4.3-4.0	0.00400	0.00384	Carman and
1-9	1-5.6-5.1	0.00574	0.00352	Nelson (11)

## VARIATION WITH RELATIVE WATER CONTENT

Mixture	Relative water con- tent, %	k		
		50°C to 100°C	100°C to 200°C	200°C to 300°C
1:2	100	0.00365	0.00322	0.00320
	110	0.00300	0.00332	0.00310
	120		0.00317	
1:3	100	0.00347	0.00365	0.00340
	110	0.00343	0.00391	
	120	0.00353	0.00345	0.00310
1:4	100		0.00357	
	110	0.00415	0.00373	0.00322
	120	0.00410	0.00316	
1:5	100		0.00353	
	110	0.00381	0.00380	0.00380
	120	0.00273	0.00305	0.00270
1:7	110	0.00402	0.00387	
	120		0.00300	
1:9	110	0.00573	0.00359	Carman and
	120		0.00273	Nelson (11)

## EFFECT OF AGE (11)

Mix- ture	Rela- tive water content %	Age days	k	Mix- ture	Rela- tive water content %	Age days	k
1:2	110	28	0.00335	1:5	120	28	0.00330
		120	331			120	297
1:3	110	28	398	1:7	110	28	380
		120	365			120	380
1:4	110	28	376	1:9	110	28	340
		120	337			120	387

For additional data, see p. 122.

## Thermal Diffusivity (11)

DIFFUSIVITY OF CONCRETE, 100°-200°C

Relative water content, 110%

Mixture	Density g cm <sup>-3</sup>	k	Specific heat cal g <sup>-1</sup> °C <sup>-1</sup>	Diffusivity cm <sup>2</sup> sec <sup>-1</sup>
"Neat"	1.83	0.00147	0.278	0.00289
1-2	2.26	0.00344	0.216	0.00705
1-3	2.28	0.00379	0.218	0.00762
1-4	2.29	0.00352	0.218	0.00705
1-5	2.29	0.00323	0.217	0.00650
1-7	2.23	0.00384	0.227	0.00758
1-9	2.16	0.00352	0.223	0.00732

## Setting Time

In the U. S., the standards of the Govt. and Amer. Eng. Stands. Com. require an initial set in not less than 1 hour, and a final set within 10 hours, as determined by a purely empirical test. In other countries cements may be made to meet various specification requirements as to setting (cf. p. 117). No method of measuring the set of mortars or concretes has been developed.

## Time Rate of Change of Volume

These data have been obtained by linear measurements alone, and are as usual faulty, owing to lack of data that would accurately delimit the concrete under investigation. The change is among other variables a function of the size of specimen, amount of water used, and the humidity of the surrounding atmosphere. The values given indicate a contraction ranging from 0.018 to 0.08% for "reinforced concrete" (33).

## Resistance to Weathering and Chemical Action

Mortars and concretes are attacked by acid. If dense and carbonated on the exterior they offer great resistance to weather and other chemical agents.

## TESTS OF PORTLAND CEMENT

Used in obtaining the data given in Tables 2, 3, 4, and 5.

The cement used in all tests consisted of a mixture of equal parts of four brands purchased in Chicago and gave satisfactory soundness tests (over boiling water).

Tests were made in accordance with the *Standard Specifications and Tests for Portland Cement*, A. S. T. M.

## Miscellaneous tests

Fineness. Residue on No. 200 Tyler Sieve %	Normal consistency wt. %	Time of setting							
		Vicat needle				Gillmore needle			
		Initial	Final	Initial	Final	Initial	Final	Initial	Final
18.8	24.0	3	40	8	20	5	45	9	40
17.6	23.0	3	45	8	00	6	30	8	30

## Mortar strength tests

## 1:3 Standard Sand Mortar.

Mixing water %	Tensile strength (Def. 4) of briquets, lb./in. <sup>2</sup>					Compressive strength (Def. 4) 2 × 4 in. cylinders, lb./in. <sup>2</sup>				
	7 da	28 da	3 mo	6 mo	1 yr	7 da	28 da	3 mo	6 mo	1 yr
10.5	235	365	425	380	405	1670	2570	3520	4250	3840
10.3	280	430	410	385	355	1720	2870	3710	4150	4370

## TABLE 2.—EFFECT OF CURING CONDITION OF CONCRETE

Mix, 1:4 by volume. Relative consistency of concrete, 1.10; water-ratio, 0.82. Age at test, 28 days.

Aggregate: sand from Janesville, Wis., and pebbles from Elgin, Ill.; graded up to 1½ in. Each value is the average of 5 tests made on different days.

Ref. No.*	Days storage		Modulus of rupture of beams, lb./in. <sup>2</sup>	Compressive strength of 6 × 12 in. cylinders, lb./in. <sup>2</sup>	Modulus of rupture % compression
	Damp burlap	Dry air			
7, 8	28	0	550†	2580†	21.3
42	26	2	510	2630	19.4
43	21	7	450	2850	15.8
44	14	14	485	2920	16.6
45	7	21	470	3020	15.6
46	4	24	410	2330	17.6
47	0	28	370	2340	15.8
Average			465	2670	17.5

\* See Table 1 for Ref. Nos.

† Average of 25 beam tests and 115 cylinder tests.



TABLE 1.—SIEVE ANALYSIS AND UNIT WEIGHT OF AGGREGATES

Used in obtaining the data given in Tables 2, 3, 4, and 5.

Square mesh wire cloth sieves, Tyler Series (*v. p.* 329), were used in making sieve analyses. Each sieve has a clear opening twice the width of the preceding one.

Ref. No.	Aggregate		Sieve analysis									Fineness modulus of aggre- gate*	Unit weight, lb./ft. <sup>3</sup>
	Kind	Size No.	Wt. % retained on each sieve										
			100	50	30	16	8	4	$\frac{3}{8}$	$\frac{3}{4}$	1½		
36	Janesville sand.....	0-No. 16	97	78	20	0						1.95	108
37		0-No. 8	98	80	28	11	0					2.17	111
38		0-No. 4	98	82	35	19	9	2	0			2.45	113
39		0-0.375 in.	99	90	63	54	49	45	0			4.00	123
40		0-0.75 in.	99	93	75	69	64	61	39	0		5.00	128
1-28, 41		0-1.5 in.	99	95	80	76	74	71	52	18	0	5.65	130
29	Janesville sand and Elgin pebbles....	0-1.5 in.	98	84	43	30	20	14	8	3	0	3.00	118
30		0-1.5 in.	99	88	57	46	41	35	25	9	0	4.00	127
31		0-1.5 in.	99	90	64	56	51	46	33	11	0	4.50	131
32		0-1.5 in.	99	92	71	65	61	57	41	14	0	5.00	132
33		0-1.5 in.	99	93	75	70	66	62	45	15	0	5.25	133
34		0-1.5 in.	100	96	86	83	80	78	58	19	0	6.00	127
35		0-1.5 in.	100	97	89	86	85	84	63	21	0	6.25	124
42-53	Janesville sand and Elgin pebbles.....	0-1.5 in.	99	95	80	76	74	71	52	18	0	5.65	130
59-64													
54	Janesville sand and crushed slag.....	0-1.5 in.	99	95	80	76	74	71	52	18	0	5.65	118
55	Janesville sand and crushed limestone....	0-1.5 in.	99	95	80	76	74	71	52	18	0	5.65	129
56	Janesville sand and crushed granite.....	0-1.5 in.	99	95	80	76	74	71	52	18	0	5.65	121
57	Washed Elgin sand and Elgin pebbles....	0-1.5 in.	99	95	86	80	72	67	49	17	0	5.65	127
58	Unwashed Elgin sand and Elgin pebbles..	0-1.5 in.	100	98	91	86	81	73	50	18	0	5.97	130

\* Sum of per cents in sieve analysis, divided by 100.

TABLE 3.—EFFECT OF QUANTITY OF CEMENT AND MIXING WATER

Aggregate: sand from Janesville, Wis., and pebbles from Elgin, Ill.; graded up to  $1\frac{1}{2}$  in. Fineness modulus, 5.65. Age at test, 28 da. Specimens tested damp. Each value for modulus of rupture is the average of 10 tests, and for compressive strength 20 tests, made on 10 different days.

Ref. No.	Mix by volume	Cement vol. % of concrete	Relative consistency	Water-ratio of concrete	Modulus of rupture of beams, lb./in. <sup>2</sup> (7 in. deep, 10 in. wide, 38 in. long)			Compressive strength of 6 × 12 in. cylinders, lb./in. <sup>2</sup>	Modulus of rupture, % compression
					Bottom*	Top*	Aver.		
Effect of quantity of cement									
1, 2	1:6	16.4	1.10	1.03	430	420	425	1820	23.4
3, 4	1:5	19.0	1.10	0.92	500	490	495	2140	23.1
5, 6	1:4.5	20.7	1.10	0.87	480	510	495	2130	23.2
7, 8	1:4	23.0	1.10	0.82	560	540	550†	2580†	21.3
9, 10	1:3.5	25.4	1.10	0.76	590	540	565	2980	19.0
11, 12	1:3	28.7	1.10	0.71	600	590	595	3480	17.1
13, 14	1:2.5	33.0	1.10	0.64	590	590	590	4110	14.3
15, 16	1:2	38.7	1.10	0.59	660	620	640	4390	14.6
				Average . . . .	550	540	545	2950	19.5
Effect of quantity of mixing water									
17, 18	1:4	23.8	0.90	0.68	590	560	575	3760	15.3
19, 20	1:4	23.5	0.95	0.72	580	600	590	3280	18.0
21, 22	1:4	23.4	1.00	0.75	580	560	570	3100	18.4
23, 24	1:4	23.2	1.05	0.78	570	550	560	2720	20.6
7, 8	1:4	23.0	1.10	0.82	560	540	550†	2580†	21.3
25, 26	1:4	22.5	1.25	0.92	460	540	500	1920	26.0
27, 28	1:4	22.3	1.50	1.08	400	500	450	1300	34.6
				Average . . . .	535	550	540	2660	22.0

\* Part of concrete beam (as molded) which was exposed to tensile stress during loading.

† Average of 25 beam tests and 115 cylinder tests.

TABLE 4.—EFFECT OF SIZE AND GRADING OF AGGREGATE

Aggregates: sand from Janesville, Wis., and pebbles from Elgin, Ill. Aggregates of different size were obtained by separating sand and pebbles into various sizes and recombining as shown by sieve analyses in Table 2. Different gradings of aggregates were produced by mixing sand (0 to No. 4) and pebbles (No. 4 to 1½ in.) in different proportions.

Mix, 1: 5 volume. Relative consistency, 1.10. Specimens tested damp. Each value is the average of 5 tests made on different days.

Ref. No.	Aggregate		Water-ratio of concrete	Modulus of rupture of beams, lb./in. <sup>2</sup>				Compressive strength 6 × 12 in. cylinder, lb./in. <sup>2</sup>				Modulus of rupture % compression			
	Size	Fineness Modulus		7 da	28 da	3 mo	1 yr	7 da	28 da	3 mo	1 yr	7 da	28 da	3 mo	1 yr
Effect of size of aggregate															
36	0-16	1.95	1.29	95	160	255	340	270	620	1190	1600	35.2	25.8	21.5	21.2
37	0-8	2.17	1.25	95	195	320	370	360	850	1470	1860	26.4	23.0	21.8	19.9
38	0-4	2.45	1.20	125	250	370	425	430	1010	1620	2100	29.4	24.8	22.8	20.2
39	0-0.375	4.00	0.98	290	455	595	640	1040	2110	2930	4490	27.9	21.6	20.3	14.3
40	0-0.75	5.00	0.87	365	560	730	775	1290	2650	3650	4890	28.3	21.2	20.0	15.9
41	0-1.5	5.65	0.82	420	550*	810	880	1410	2580*	3590	5000	29.8	21.3	22.6	17.6
			Average...	230	360	510	570	800	1640	2410	3320	29.5	22.9	21.5	18.2
Effect of grading of aggregate															
29	0-1.5	3.00	1.11	165	255	410	450	620	1290	1640	2330	26.6	19.8	25.0	19.3
30	0-1.5	4.00	0.98	230	390	505	570	950	2000	2550	3230	24.2	19.5	19.8	17.7
31	0-1.5	4.50	0.93	285	485	610	645	1090	2190	2750	3830	26.2	22.2	22.2	16.9
32	0-1.5	5.00	0.87	325	505	660	710	1160	2410	3580	4510	28.0	21.0	18.4	15.8
33	0-1.5	5.25	0.85	365	555	735	820	1320	2940	3810	5340	27.7	18.9	19.3	15.4
41	0-1.5	5.65	0.82	420	550*	810	880	1410	2580*	3590	5000	29.8	21.3	22.6	17.6
34	0-1.5	6.00	0.78	405	600	735	825	1300	2250	3310	4400	31.2	26.7	22.2	18.8
35	0-1.5	6.25	0.77	385	590	730	865	1140	1990	2840	4080	33.8	29.6	25.7	21.2
			Average...	320	490	650	720	1120	2210	3010	4090	28.4	22.4	21.9	17.8

\* Average of 25 beam tests and 115 cylinder tests.

TABLE 5.—EFFECT OF KIND OF AGGREGATE

Mix, 1: 4 by volume. Relative consistency, 1.10; water-ratio, 0.82.

Aggregate: sand, 0 to No. 4; and coarse aggregate, No. 4 to 1½ in.; all of same grading. Specimens tested damp. Age at test, 28 days. Each value is the average of 5 tests made on different days.

Ref. No.	Kind of aggregate		Modulus of rupture of beams, lb./in. <sup>2</sup>				Compressive strength 6 by 12 in. cylinder, lb./in. <sup>2</sup>				Modulus of rupture % compression			
	Sand	Coarse	7 da	28 da	3 mo	1 yr	7 da	28 da	3 mo	1 yr	7 da	28 da	3 mo	1 yr
7, 8	Janesville.....	Elgin pebbles.....	420	550*	810	880	1410	2580*	3590	5000	29.8	21.3	22.6	17.6
54	Janesville.....	Slag.....	450	585	765	760	1240	2300	3150	4530	36.3	25.4	24.3	16.8
55	Janesville.....	Limestone.....	440	595	790	830	1320	2350	3280	3970	33.4	25.3	24.1	20.9
56	Janesville.....	Granite.....	375	540	665	725	1010	1980	2960	3760	37.1	27.3	22.4	19.3
57	Elgin washed.....	Elgin pebbles.....	405	595			1490	2640			27.2	22.5		
58	Elgin unwashed...	Elgin pebbles.....	425	610			1340	2520			31.7	24.2		
		Average.....	420	580	760	800	1300	2390	3240	4320	32.6	24.3	23.4	18.8

\* Average of 25 beam tests and 115 cylinder tests.

### GYPSUM (Plaster-of-Paris)

W. E. EMLEY

**Raw Materials and Calcination.**—Commercial gypsum should contain  $\leq 64.5\%$   $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$  (A. S. T. M., C22-23T; C23-22). On calcination below  $163^\circ\text{C}$ ,  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$  (gypsum) =  $\text{CaSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$  +  $1\frac{1}{2}\text{H}_2\text{O}$ . Gentle calcination above  $163^\circ\text{C}$ ,  $\text{CaSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$  =  $\text{CaSO}_4$  (soluble anhydrite) +  $\frac{1}{2}\text{H}_2\text{O}$ . At higher temperatures  $\text{CaSO}_4$  (soluble anhydrite) =  $\text{CaSO}_4$  (natural anhydrite (insol.)) (29, 44). For dissociation pressures, consult this item in the index of I. C. T. Commercial calcination and product *v.* (8, 21, 38).

**Properties.**—The properties of products made from calcined gypsum are dependent upon the nature of the calcined gypsum (purity, method of calcination, and fineness), upon the quantity of water used in placing it, and upon the kind and amount of

other materials (accelerators, retarders, lime, clay, sand) added to it. These facts must be constantly borne in mind when interpreting the figures given below.

**Setting Time.**—A normal figure is 6 min for no impression by Vicat needle (24) (A. S. T. M., C26-33). Doubling the amount of water will give 29 min (24). Fine grinding after calcination may lower to 3 min (49). The setting reaction is not complete when the Vicat needle indicates that the material is set. Evolution of heat continues and the temp. continues to rise for many min (18). If the calcined gypsum is of such a nature that a max. temp. rise of  $14^\circ\text{C}$  is attained in 53 min this time can be decreased to 21 min (by 2% sodium chloride) or increased to more than 240 min (by 2% calcium acetate) (43).

The commercial accelerator generally recommended is finely ground raw or set gypsum. The accelerating effect of this material is so powerful that especial care must be taken to clean all vessels



and tools before mixing a fresh batch of material. 0.5 to 0.6% of this material will decrease the time of set of gypsum plaster about 1 hr (48). Other soluble sulfates, such as are generally found in our water supplies, have similar effects.

Commercial retarder is a mixture made by cooking together soda, lime, and slaughter house refuse; 0.2% of this material will retard the time of set 2.5 to 3 hr (43). Carpenters' glue has a similar effect and is more readily obtainable.

**Expansion on Setting.**—Calcined gypsum will normally expand when it sets. Heavily retarded material may contract due to settling out of the solid. Calcined gypsum retarded to set in 2 hr and mixed with 35% water expanded 0.15% in length while setting. Increasing the water to 47% increased the expansion to 0.30%. Addition of sand seemed to have little effect.

After the gypsum has set and dried, wetting will cause expansion, drying, contraction. The magnitude of the movement is about 0.04% for the pure material. Addition of sand reduces this expansion, the reduction being proportional to the amount of sand, so that a specimen made of one part calcined gypsum to a little more than two parts of sand shows practically no movement, and leaner mixtures actually contract instead of expanding on being wetted (35).

**Strength.**—Calcined gypsum, if pure, properly calcined, of such fineness that it will all react, mixed with as little water as possible to bring it to a pouring consistency, molded in the form of a cylinder 2 in. diameter by 4 in. high, not retarded to such an extent that much water can evaporate prior to setting, and stored in a cool place until dry, will develop a compressive strength of at least 1000 lb./in.<sup>2</sup> (A. S. T. M. C23-22); av. 1665, max. 2285 (21).

Naturally occurring impurities or added materials (except accelerators) will decrease the strength. The average figure for the compressive strength of a mixture of one part calcined gypsum to two parts sand by weight may be taken at 415 lb./in.<sup>2</sup> (21); for a 1:3 mixture the figure is 335. Lime and clay reduce the strength at early ages, but this is gradually recovered (36). Portland cement reduces the strength in proportion to the cement added until the mixture reaches a minimum at 20% gypsum 80% cement, the strength of which is little more than half that of calcined gypsum (35).

Increased fineness up to 80% through a No. 100 U. S. Standard sieve (v. p. 329), by making the calcined gypsum more reactive, causes increased strength. This size is 50% stronger than material only 40% of which passes a No. 100 sieve. Further increase in fineness is accompanied by a decrease in strength because more water is required to bring the mixture to a workable consistency (45).

The above figures are based on the max. consistency thickness which will allow pouring. Thicker consistencies will give greater strength, clear to the limit of workability of the mixture (9). Thinner consistencies will give lower strengths to zero, for calcined gypsum will not harden under water.

While there is a tendency for accelerators to increase the strength of calcined gypsum and for retarders to reduce it, the action of neither is marked unless retarder is present in sufficient amount to delay the set until the water required for setting has evaporated. Two per cent calcium acetate, for example, will retard calcined gypsum so far as to destroy completely its strength (43).

Castings made of calcined gypsum are strongest when completely dry. Moisture, or more particularly percolating water, seems to dissolve the bond between the crystals, resulting in permanent loss of strength or eventual disintegration. On account of the comparatively high dissociation pressure of gypsum at ordinary temperatures (100 mm Hg at 62°C) (41), it is dangerous to resort to artificial drying. The strength reaches very nearly its maximum as soon as the casting is dry, so that the age of a test specimen is of little importance (A. S. T. M. C26-23).

The ratio compressive strength/tensile strength = *ca.* 4.62 (21).  
**Thermal Conductivity and Fire Resistance.**—(25). (*See also* p. 315.)

**Heat of Dehydration.**—*See* I. C. T. Section on Thermochemistry.

**Porosity, Solubility and Weather Resistance.**—Calcined gypsum will not harden under water. When hardened in air and immersed in running water, castings made of calcined gypsum will eventually disintegrate. Calcined gypsum should not be used in situations where it will be exposed to the weather unless special precautions are taken.

These characteristics are usually attributed to the fact that gypsum is "quite soluble," but it is now believed that they are dependent more upon porosity than solubility.

The solubility of gypsum in pure water varies from 0.18% at 0°C to a maximum of 0.21% at 40°C, but it is much more soluble in water containing certain common salts (23). Taking the weight of set gypsum at 77 lb./ft.<sup>3</sup> (32) and the specific gravity of the solid material at 2.35, the pores must occupy 47.5% of the total volume. (This figure may vary within wide limits, depending upon the fineness of the calcined gypsum and the quantity of mixing water used.) Owing to the crystalline nature of the material, these pores are comparatively large and afford passages for circulation of water, thereby rendering material assistance in the solution of the gypsum.

It has been found that if calcined gypsum is heavily retarded so that it can be trowelled frequently while setting, the dense surface thus produced is quite effective in improving the weather resistance of the finished product (46).

## LIME MORTAR AND MASONRY

W. E. EMLEY

Commercial limes and mortars are made by mixing properly calcined limestone with water, or water and sand. Their properties depend on many variables, lack of control of which render most of the published quantitative data valueless. For the available qualitative information, reference should be made to the literature cited.

### Raw Materials

**Nature of Raw Materials, Commercial Definitions and Specifications** (12).—(A. S. T. M. C51-22T; C5-22T).

**Density.**—v. p. 53.

**Porosity.**—Limestone usually less than 1 vol. % (v. p. 53).

**Dissociation Pressure and Rate of Dissociation.**—The dissociation pressure reaches 1 atm at 898°C for CaCO<sub>3</sub> and 756.5°C for MgCO<sub>3</sub>. For further data, v. "Dissociation pressure" in the index of I. C. T. Commercial calcination is *ca.* 6 hr at *ca.* 1400°C (6, 15).

**Other Properties.**—*See* the pure materials in the various tables of I. C. T. *See also* p. 47.

### Hydrated Lime and Lime Putty

**Manufacture.**—When CaO is properly mixed with an excess of water sufficient to keep the temp. below 100°C "lime putty" is obtained. With less excess, the resultant product is dry "hydrated lime." With still less water, the temperature may rise above 375°C and an "oxyhydrate" is obtained (17, 26).

**"Plasticity."**—(20, 25, 26, 28).

### Lime Mortars

**Decrease in Volume on "Setting."**—From 9% for non-plastic to 27% for plastic lime putty (28). This contraction is in practice reduced to *ca.* 5% by admixture of 80-90% of sand (5, 40).

**Setting Time.**—No agreement as to definition of term. The following laboratory test has been proposed (37):

Setting shall be assumed to be attained when an electrical resistance of 30 000 ohms is reached between two 5 mm brass plugs imbedded 8 mm in the plaster with their centers 10 cm apart.



Under this definition, neat lime putty will set in 40–50 hr, and this may be reduced 5–10 hr by admixture of sand (37).

**Rate of Carbonation.**—As ordinarily mixed and placed, lime mortar will carbonate from the surface inwards at *ca.* 1/8 in. per month (16). This is subject to change, within narrow limits, by variations of the factors enumerated above. A 2-in. cube exposed on 5 sides will carbonate completely in *ca.* 8 months; an 8-in. mortar joint exposed on one side will require more than 5 years.

**Soundness.**—(20, 31, 47).

**Strength.**—For purposes of intercomparison only, the following figures may be quoted as the strength of a mortar made of high calcium hydrate with three parts by weight of run-of-mine Ottawa sand and enough water to bring the mixture to "Standard" consistency (19) on the plunger viscometer, the mortar being molded in the form of 2-in. cubes for compression, the usual type of briquette for tension, and 12 × 1 × 1 in. bars for transverse and shear, and the specimens stored in the laboratory, with 5 sides exposed, for 90 days: Compressive, 403; Tensile, 69; Shearing, 82; Transverse, 146 lb./in.<sup>2</sup>

**Expansion after Setting.**—No published data. Humidity and thermal coefficients at room temperature approximately equal to those of concrete. Thermal coefficient much greater at higher temperatures (9).

**Strength of Masonry (7, 13).**—Common brick masonry (1 to 4 pt. by vol. lime mortar) should withstand a compression of 125 lb./in.<sup>2</sup> (14). See also p. 66.

**Thermal Conductivity and Fire Resistance.**—(25).

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(For a key to the periodicals see end of volume)

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## MAGNESIA CEMENTS AND CONCRETES

LEROY C. STEWART

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### BULK DENSITY (7)

Grams per cm<sup>3</sup>: Stucco, 3.0 to 3.4. Flooring, 1.55 to 1.8. Special mixes with wood flour, cork dust, etc., 1.0 to 2.0.

### ULTIMATE TENSILE STRENGTH (DEF. 4) AND MODULUS OF RUPTURE (DEF. 5) OF CEMENTS MADE WITH SPECIALLY CALCINED DOLOMITES

Wt. %: Calcined dolomite 31, ground flint 12.5, Ottawa sand 56.5. 1.179 sp. gr. MgCl<sub>2</sub> soln., kg/cm<sup>2</sup> (22).

Dolomite	Tensile strength			Modulus of rupture*		
	1 day	3 days	7 days	Not sprayed	Wet	Recovered
A			32.6	112.2	54.0	68.0
B	18.1	30.2	34.4	133.0	69.6	102.6

\* Bars sprayed 24 hr at 14, 16 and 18 days' age. "Wet" bars broken at 19 days' age and "Recovered" at 21 days' age. "Not Sprayed" bars broken at 20 days' age.

### ELASTIC PROPERTIES

Elastic limit (Def. 2), modulus of elasticity (Def. 10a) and ultimate compressive strength (Def. 4) of cement mortar and concrete.

1.23 sp. gr. MgCl<sub>2</sub> soln. used. Aged 80–85 days. Unit kg/cm<sup>2</sup> (1).

Magnesite-sand-rock by wt.	Elas. lim.	Mod. elas.	Compr. str.
1–4–0	253	194 000	319
1–6–0	150	192 000	240
1–8–0	127	146 000	185
1–10–0	53–114	96 400	143
1–2–4	234	269 000	359
1–3–6	234	194 000	305



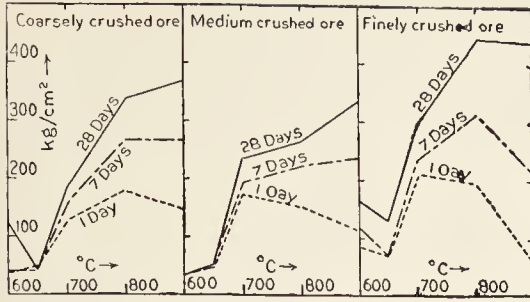


FIG. 1.—Ultimate compressive strength (Def. 4) of magnesium oxychloride flooring mixtures as affected by size and burning temperature of magnesite ore (3).

Graphs in Figs. 1 and 2 represent averages of three compositions, using  $MgCl_2$  solution (sp. gr. 1.184) and Washington magnesite. Coarse ore passed 3.35 mm sieve, retained on 2.00 mm; medium passed 2.00 mm, retained on 0.585 mm; fine passed 0.249 mm opening.

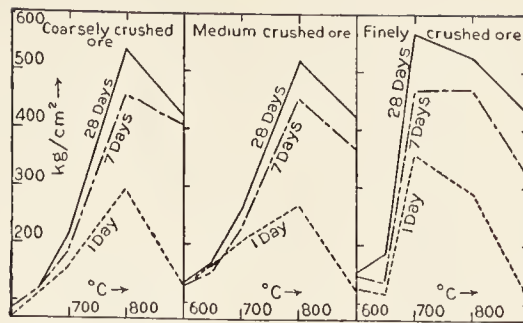


FIG. 2.—Ultimate compressive strength (Def. 4) of magnesium oxychloride mortar mixtures as affected by size and burning temperature of magnesite ore (3).

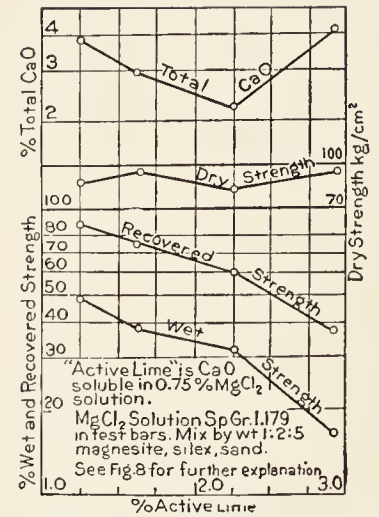


FIG. 9.—Effect of active lime in magnesite on magnesium oxychloride cement (21).

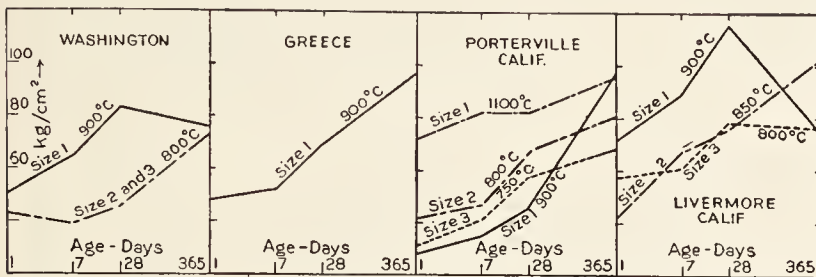


FIG. 3.—Modulus of rupture (Def. 5) of magnesium oxychloride flooring mixture as affected by source, size and burning temperature of magnesite ore (4).

Sizes of magnesite: 1, passing 2.54 cm, retained on 1.27 cm screen; 2, passing 1.27 cm, retained on 0.64 cm screen; 3, passing 0.64 cm, retained on 0.32 cm screen. Mix: 45 %  $MgO$ , 10 % wood flour, 5 % asbestos, 20 % silice, 5 % silocel, 5 % clay, 10 % pigment (all by weight);  $MgCl_2$  soln., sp. gr. 1.179.

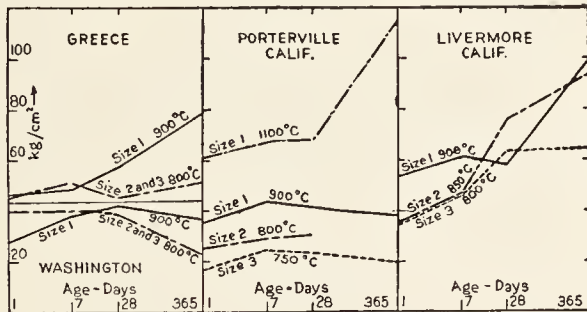


FIG. 4.—Modulus of rupture (Def. 5) of magnesium oxychloride stucco mixture as affected by source, size and burning temperature of magnesite ore (4).

Sizes as in Fig. 3. Mix: 10 %  $MgO$ , 20 % silice, 67 % mortar sand, 3 % asbestos (all by weight);  $MgCl_2$  soln., sp. gr. 1.179.

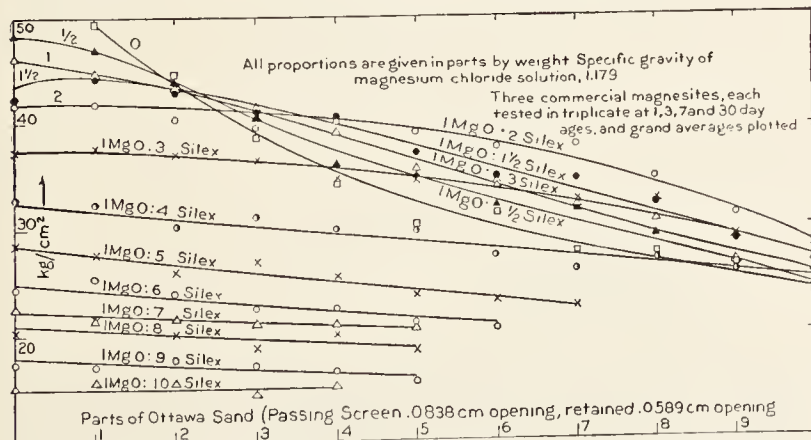


FIG. 7.—Tensile strength of oxychloride-silice-sand mixtures (8).

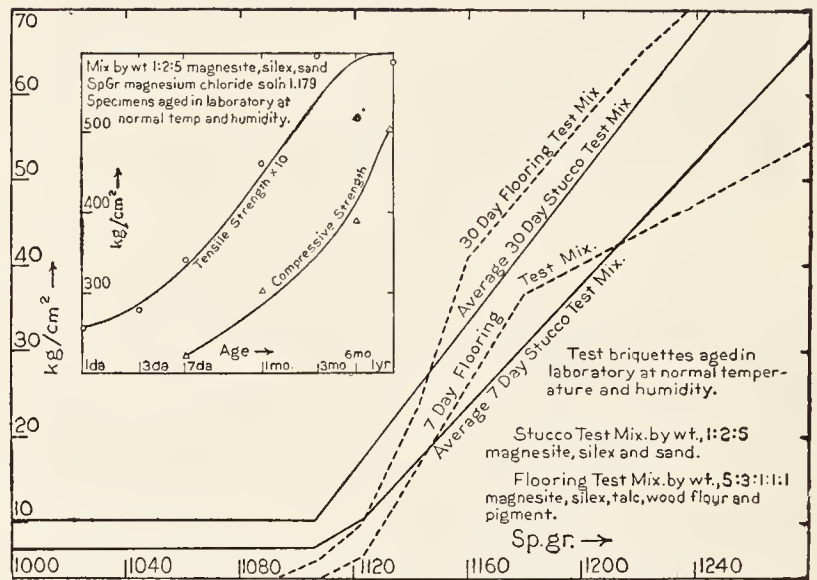


FIG. 5 (Insert).—Strength of magnesium oxychloride cements (7). Average for 12 commercial magnesites.

FIG. 6.—Effect of magnesium chloride solution strength on tensile strength of oxychloride cements (11).

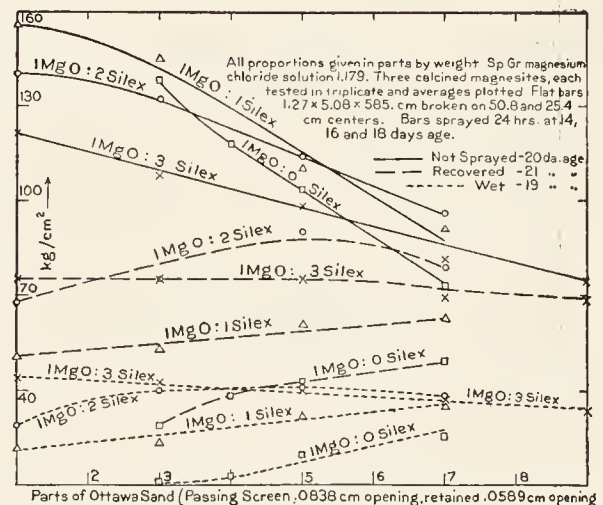


FIG. 8.—Water resistance of oxychloride-silice-sand mixtures. Modulus of rupture (10).

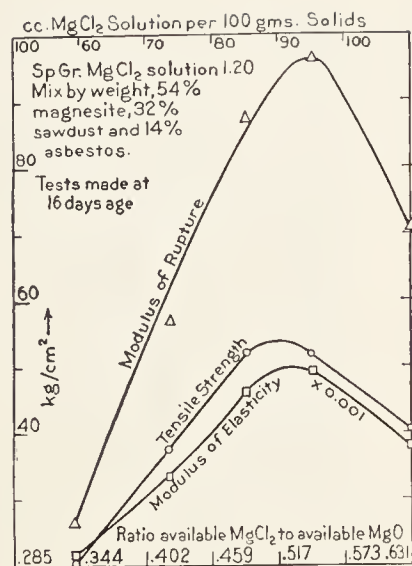


FIG. 10.—Effect of variation in amount of magnesium chloride solution on strength and elasticity of magnesium oxychloride flooring (19).

Modulus of elasticity  $= Pl^3/4dbh^3$ , where  $P$  = load applied at center,  $l$  = length of bar between supports,  $d$  = deflection of supports at center,  $b$  = width of bar and  $h$  = thickness of bar.

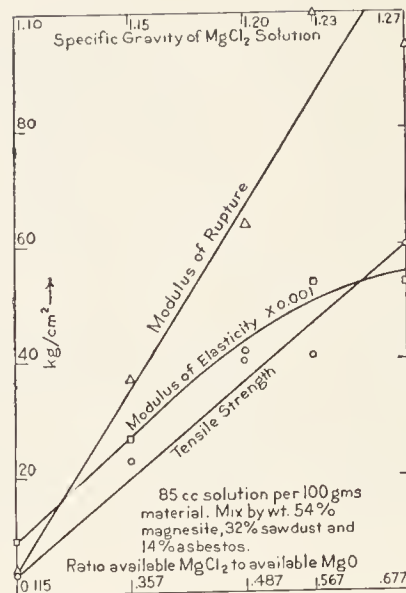


FIG. 11.—Effect of variation in density of magnesium chloride solution on strength and elasticity of magnesium oxychloride solution (19).

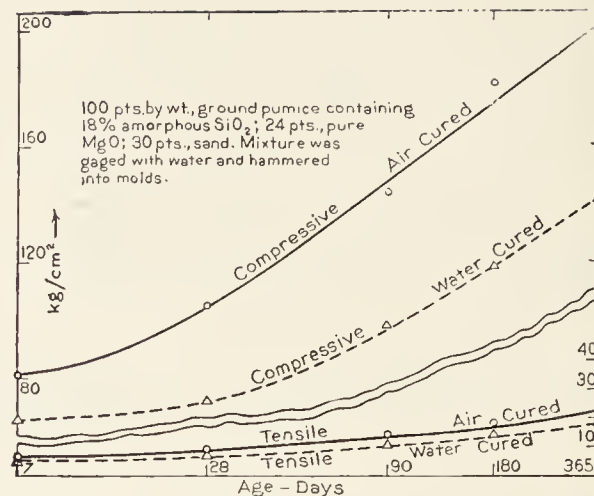


FIG. 15.—Tensile and compressive strengths of an hydraulic magnesian cement (24).

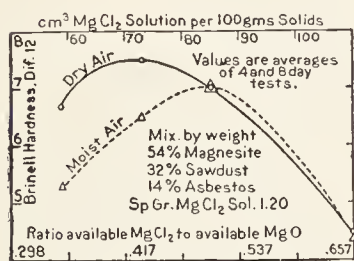


FIG. 12.—Effect of variation in amount of magnesium chloride solution on Brinell hardness of magnesium oxychloride flooring (19).

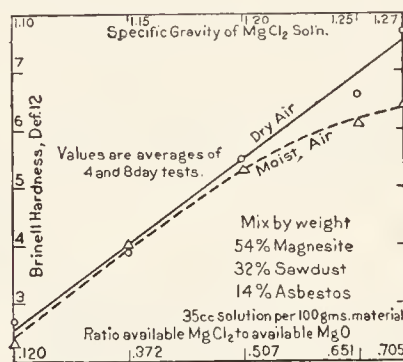


FIG. 13.—Effect of variation in density of magnesium chloride solution on Brinell hardness of magnesium oxychloride flooring (19).

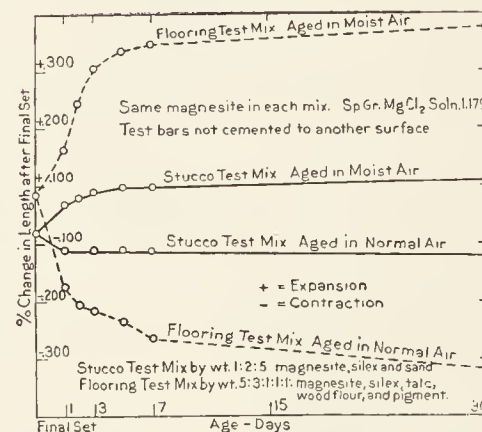


FIG. 16.—Volume change in magnesium oxychloride cements (7).

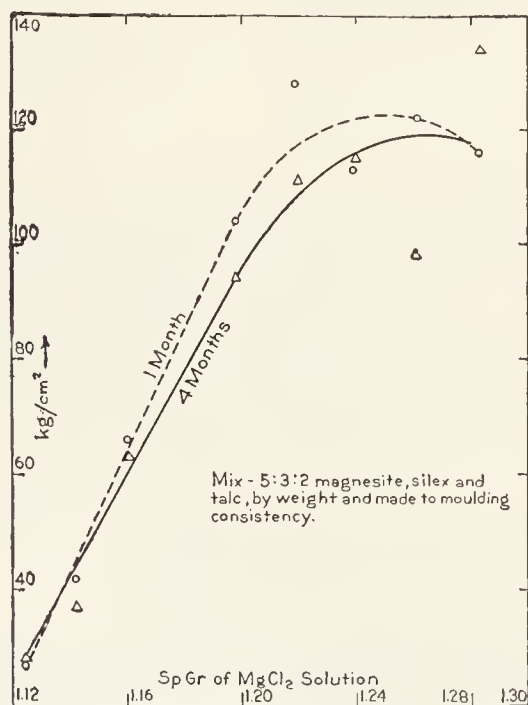


FIG. 14.—Tensile strength of high magnesite oxychloride mixtures as affected by density of magnesium chloride solution (7).

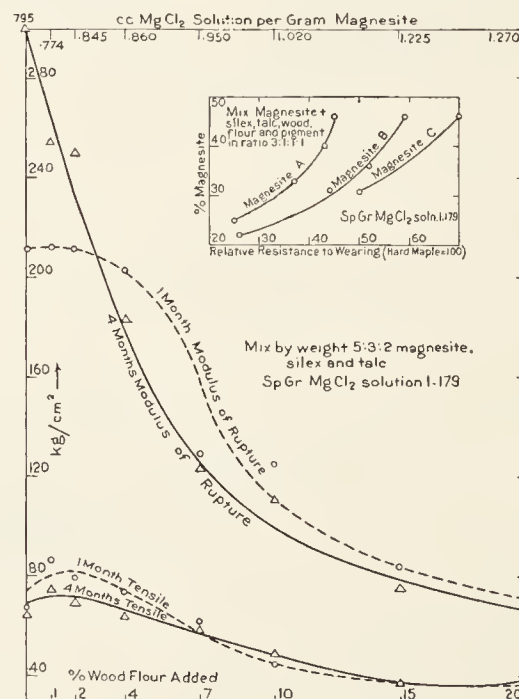


FIG. 17.—Effect of wood flour on strength of magnesium oxychloride cement mixture (7).

FIG. 18 (Insert).—Effect of % of magnesite on wearing resistance of magnesium oxychloride flooring (12).



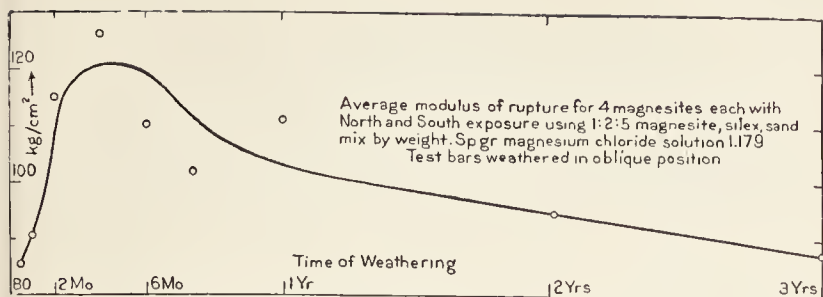


FIG. 19.—Permanency of magnesium oxychloride cement under exterior weathering (7).

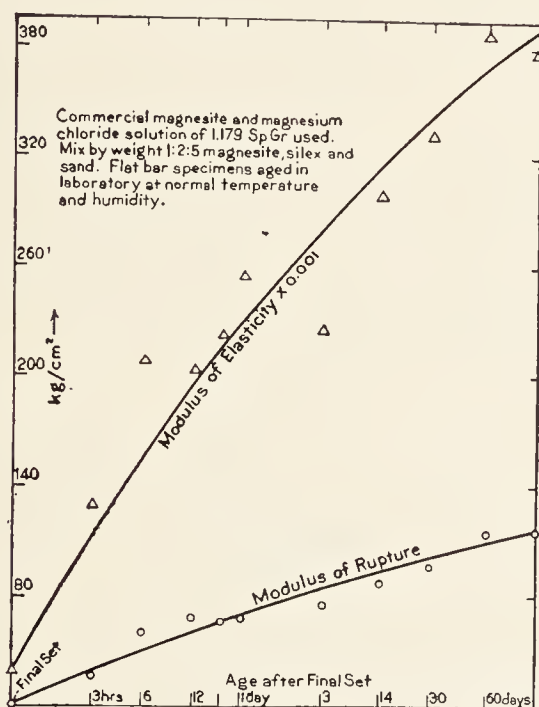


FIG. 20.—Transverse strength and elasticity of magnesium oxychloride cement at various ages (7).

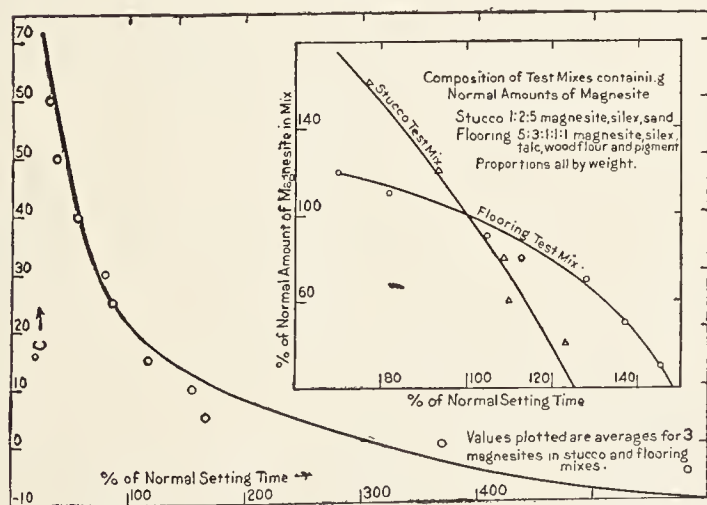


FIG. 21.—Effect of temperature on setting time of magnesium oxychloride cements (9).

FIG. 22 (Insert).—Effect of magnesite proportion on setting time of magnesium oxychloride cements (9).

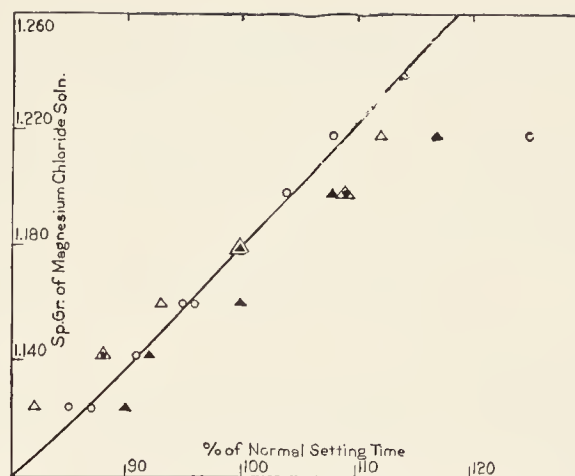


FIG. 23.—Effect of magnesium chloride solution strength on setting time of oxychloride cement (9).

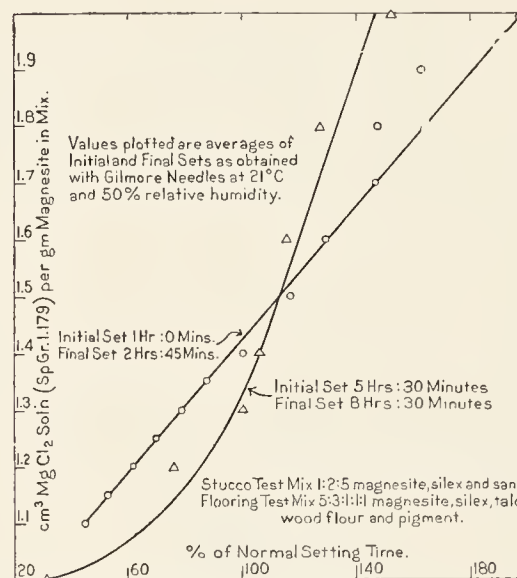


FIG. 24.—Effect of consistency on setting time of magnesium oxychloride cements (9).

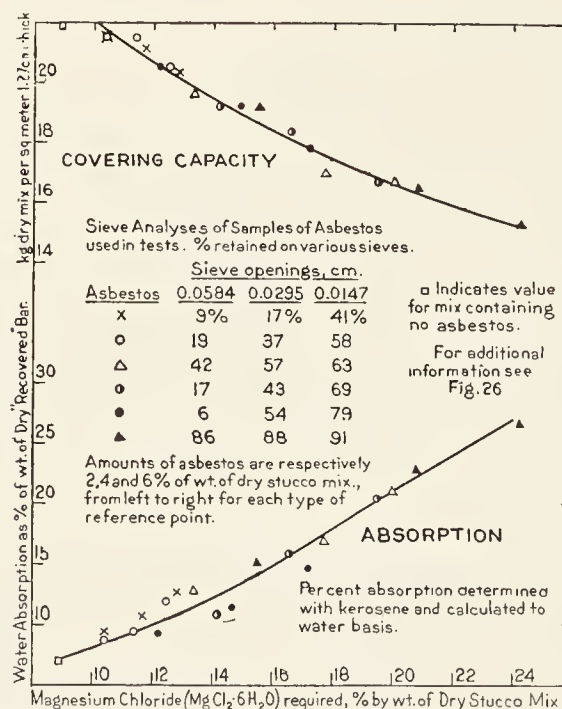


FIG. 25.—Effect of kind and amount of asbestos on covering capacity and absorption of magnesium oxychloride stucco (7).

## COEFFICIENT OF STATIC FRICTION OF COMMERCIAL MAGNESIUM OXYCHLORIDE FLOORING (7)

	Coefficient of friction
Flooring on flooring.....	0.35-0.50
Leather on flooring.....	0.45-0.70
Wood (parallel to grain) on flooring.....	0.25-0.50

## WEARING RESISTANCE

Effect of fiber variation on wearing resistance of magnesium oxychloride flooring (12).

Wt. %: Magnesite 46, silex 27, talc 9, fiber 9, pigment 9; 1.179 sp. gr.  $MgCl_2$  soln. Wearing resistance of hard maple taken as 100 (12).

Fiber	Asbestos	White pine	Hard maple	Oak	Calif. red-wood	Cork	
	Long fiber	Medium fiber	Short fiber	Sawdust	Flour	Sawdust	Flour
	Sawdust	Flour	Sawdust	Flour	Sawdust	Flour	Granulated
	Flour	Sawdust	Flour	Sawdust	Flour	Granulated	Flour
	Hard yellow pine sawdust						
Wear. resist. ....	61	55	47	50	42	40	31
	45	41	43	38	56	50	43

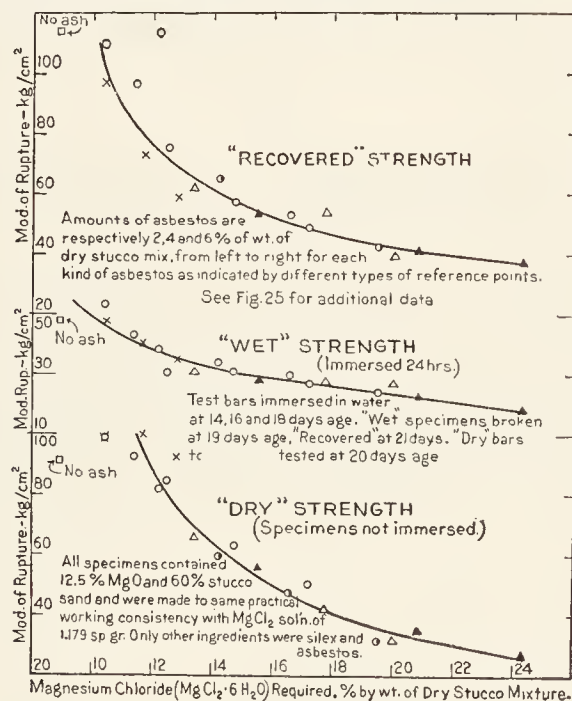


FIG. 26.—Effect of kind and amount of asbestos on water resistance of magnesium oxychloride stucco (7).

## COEFFICIENT OF LINEAR THERMAL EXPANSION

Dry ingredients by weight	Sp. gr. $MgCl_2$ solution	$\frac{10^6 l}{l \Delta t}$	$\Delta t^\circ C$	Lit.
1 magnesite : 4 sand.....	1.23	12.60	13-93	(1)
1 magnesite : 6 sand.....	1.23	11.4	13-93	(1)
54 magnesite : 32 sawdust : 14 asbestos .....	1.20	22.7	Room	(19)
1 magnesite : 2 silex : 5 sand..	1.179	15.1	4-51	(18)

## SPECIFIC HEAT AND THERMAL CONDUCTIVITY OF CEMENT MORTARS (1)

By wt. mag.-sand	Sp. gr. $MgCl_2$ soln.	$c_p$ , cal $g^\circ C$	$k$ , cal $cm^{-2} sec^{-1} (^\circ C cm^{-1})^{-1}$
1-4	1.23	0.19	0.0042
1-6	1.23	0.20	0.0045

(See also p. 314.)

## HEAT EVOLVED DURING MIXING AND SETTING OF MAGNESIUM OXYCHLORIDE CEMENTS (7)

150 to 250 g-cal per gram of commercially calcined magnesite.

## ELECTRICAL RESISTANCE OF CEMENT MORTARS

1.23 sp. gr.  $MgCl_2$  solution.  $R$  for various ages in megohm-cm (1)

Magnesite-sand by wt.	2 days	2 mo. dry	2 mo. wet
1-4	0.025	200	0.0012
1-6	0.032	138	0.001

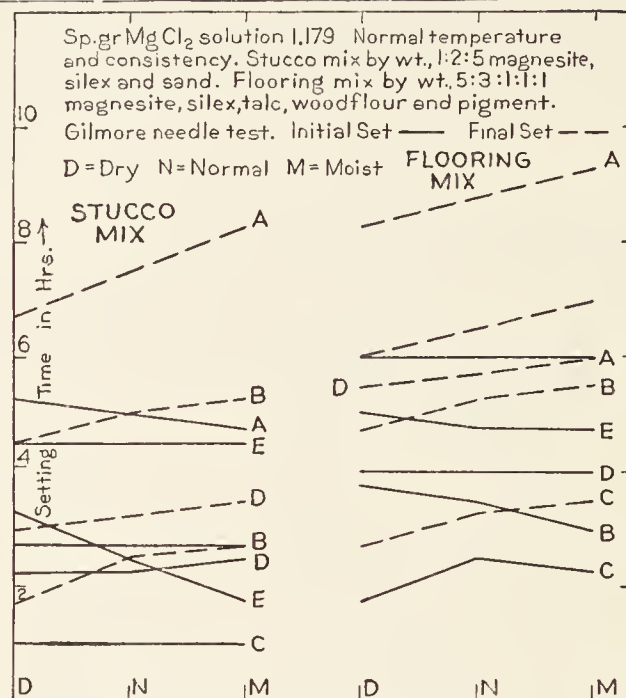


FIG. 27.—Effect of humidity on setting time of magnesium oxychloride cements (9).

## SETTING TIME OF COMMERCIAL MAGNESITES IN VARIOUS MIXES (9)

Sp. gr.  $MgCl_2$  soln. 1.179. Normal temperature, humidity and consistency. Stucco test mix by weight, 1:2:5 magnesite, silex and sand. Flooring test mix by weight, 5:3:1:1:1 magnesite, silex, talc, wood flour and pigment. Time of set determined with Gilmore needles.

For fourteen different samples of commercial magnesites, the initial set for neat mix varies from 0.5-6.25 hr, the final set from 1.5-16 hr; for stucco test mix, the initial set from 1-7.5 hr, final set, 2.75-11.5 hr; for flooring test mix, initial set, 1.5-8 hr, final set, 3-15 hr, depending on the nature of the magnesite.

## SETTING TIME OF MAGNESIUM OXYCHLORIDE CEMENT MIXTURES

Effect of source, size and burning temperature of magnesite ore (4). Flooring mix: Wt. %:  $MgO$  45, wood flour 10, asbestos 5, silex 20, silocel 5, clay 5, pigment 10. Stucco mix: Wt. %:  $MgO$  10, silex 20, mortar sand 67, asbestos 3. 1.179 sp. gr.  $MgCl_2$  soln. Gilmore needles.

Magnesite	Size*	$t^\circ C$	Flooring mix		Stucco mix	
			Initial	Final	Initial	Final
Source			Hr	Min	Hr	Min
Washington.....	1	900	3	45	8+	2
Washington.....	2+3	800	1	20	3	05
Greeee.....	1	900	1	15	3	00
Greeee.....	2	800			0	50
Porterville, Calif....	1	1100	1	35	3	45
Porterville, Calif....	1	900	0	30	2	55
Porterville, Calif....	2	800	1	15	2	55
Porterville, Calif....	3	750	3	15	5	00
Livermore, Calif....	1	900	2	15	4	30
Livermore, Calif....	2	850	1	10	2	50
Livermore, Calif....	3	800	1	15	2	15

\* Sizes of Magnesite: 1—passing 2.54 cm, retained on 1.27 cm screen; 2—passing 1.27 cm, retained on 0.64 cm screen; 3—passing 0.64 cm, retained on 0.32 cm screen.



## LITERATURE

(For a key to the periodicals see end of volume)

- (1) Alvarez, *Univ. Calif., Pub. in Eng.*, 1, No. 3: 21; 15. (2) Andre, 34, 94: 44; 82. (3) Bates and Young, 38, 4: 570; 21. (4) Bates, Young and Rapp, 32, No. 239; 23. (5) Bender, 25, 3: 932; 71. 13, 159: 341; 71. (6) Davis, 135, 25: 258; 72. (7) Dow Chemical Co., *O.* (8) Dow Chem. Co., *MgCl<sub>2</sub> Service Bull.*, No. 1; 22. (9) *Ibid.*, No. 2; 22. (10) Dow Chem. Co., *MgCl<sub>2</sub> Service Bull.*, No. 4; 22. (11) *Ibid.*, No. 5; 21.

- (12) *Ibid.*, No. 6; 21. (13) Hof, 136, 33: 693; 09. (14) Kallauner, 136, 33: 871; 09. 37: 1045, 1275; 13. (15) Krause, 13, 165: 38; 73. (16) Krieger, 136, 34: 246; 10. 37: 1274; 13. (17) Lahrman, 314, 35: 265; 11. (18) Olin and Peterson, 33, 31: 266; 24. (19) Roark, *Univ. Wisconsin, Eng. Expt. Sta., Bull.* 879; 17. (20) Robinson and Waggaman, 50, 13: 673; 09. (21) Seaton, Hill and Stewart, 33, 25: 270; 21. (22) Shaw and Bole, 38, 6: 311; 22. (23) Sorel, 34, 65: 102; 67. (24) Vournazos, 34, 172: 1578; 21. (25) Webber, 54, 10: 111; 91.

## DENTAL CEMENTS

W. B. HOLMES

## 1. TYPICAL CHEMICAL COMPOSITIONS, WEIGHT %

## ZINC OXIDE CEMENTS

Powder		Liquids	
ZnO.....	70-100	Sp. gr.....	1.55- 1.85
Bi <sub>2</sub> O <sub>3</sub> .....	0- 6	P <sub>2</sub> O <sub>5</sub> .....	33 -50
MgO.....	0- 9	H <sub>2</sub> O.....	45 -67
Fe <sub>2</sub> O <sub>3</sub> .....	0- 2	Al <sub>2</sub> O <sub>3</sub> .....	4 - 6
*Al <sub>2</sub> O <sub>3</sub> .....	0- 7	Na <sub>2</sub> O.....	0 - 3
*SiO <sub>2</sub> .....	0- 8		
*PO <sub>4</sub> .....	0- 2		

## SILICEOUS CEMENTS

Powder		Liquids	
SiO <sub>2</sub> .....	25-45	Sp. gr.....	1.50- 1.80
Al <sub>2</sub> O <sub>3</sub> .....	27-40	P <sub>2</sub> O <sub>5</sub> .....	35 -45
CaO.....	4-13	H <sub>2</sub> O.....	44 -70
Na <sub>2</sub> O.....	0- 8	Al <sub>2</sub> O <sub>3</sub> .....	4 - 6
*BeO.....	0-16	ZnO.....	0 - 8
PO <sub>4</sub> .....	4-24		
F.....	0-10		

## COPPER CEMENTS

Powder		Liquids	
ZnO.....	0-90	Sp. gr.....	1.50- 1.70
CuO.....	0-90	P <sub>2</sub> O <sub>5</sub> .....	33 -45
Cu <sub>2</sub> O.....	0-30	H <sub>2</sub> O.....	44 -65
Cu <sub>2</sub> I <sub>2</sub> .....	0- 5	Al <sub>2</sub> O <sub>3</sub> .....	4 - 6
Co <sub>2</sub> O <sub>3</sub> .....	0- 8	ZnO.....	0 - 4
Fe <sub>2</sub> O <sub>3</sub> .....	0-20	FeO.....	0 - 4
CuSiO <sub>3</sub> .....	0- 1	NiO.....	0 - 1
Cu <sub>3</sub> (PO <sub>4</sub> ) <sub>2</sub> .....	0- 5	CuO.....	0 - 1
*MgO.....			

2. CRUSHING STRENGTH<sup>(1)</sup>

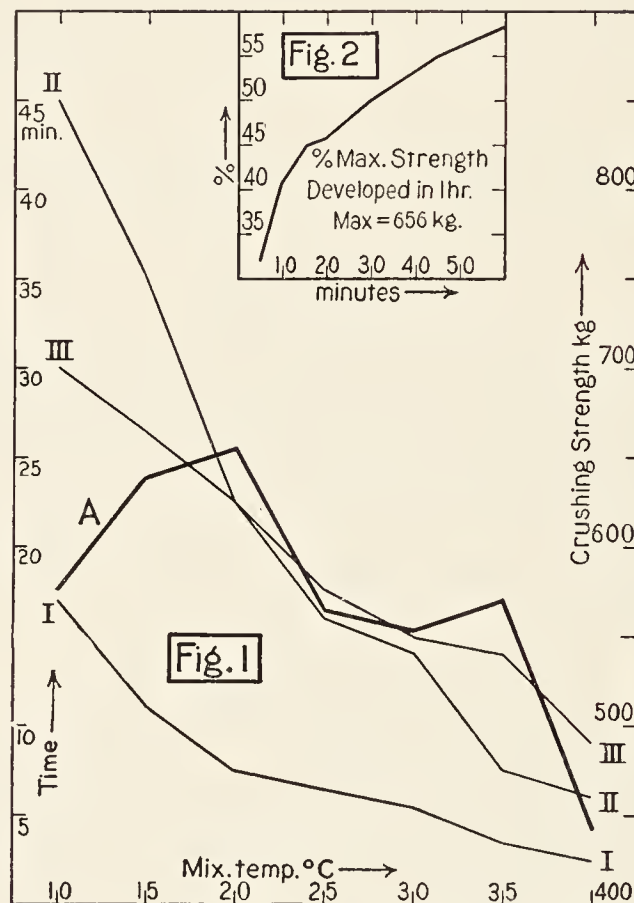
1. *Limits for Commercial Cements.*—Cement mixed at 20°C and then incubated at 37°C in oil. For the saliva tests the cylinders are incubated in oil for 15 min, then washed with petroleum ether and the incubation continued in saliva. Pressure applied to a cylinder (5 × 5 mm) at the rate of 453.6 kg/min.

Incubation:	(1) In oil for			
	15 min	1 day	7 days	28 days
Type and No. of samples tested	Crushing strength. Unit = 100 kg			
Sil. (7).....	1.5-2.8	3.3-5.6	4.1-6.3	4.0-6.5
ZnO (18).....	0.4-3.5	0.9-4.8	0.7-5.6	1.0-5.6
Cu (15).....	0.5-2.9	0.5-4.4	0.4-5.4	0.7-5.4

Incubation:	(2) In saliva for		
	1 day	7 days	28 days
Type and No. of samples tested	Crushing strength. Unit = 100 kg		
Sil. (7).....	1.0-5.6	1.1-5.9	1.2-6.6
ZnO (18).....	0.9-4.4	1.1-4.9	1.0-4.4
Cu (15).....	0.8-4.4	1.2-4.5	0.0-4.3

2. *Influence of Mixing Temperature.*—See Curve A, Fig. 1.

3. *Rate of Hardening of a "Synthetic Porcelain" Cement at 37°C as Measured by Its Crushing Strength.*—See Fig. 2, which gives the crushing strength in % of maximum strength, during the first hour.

3. SETTING TIME<sup>(1)</sup>

Time from mixing to failure of Gilmore needle to indent in 5 sec application. Seven siliceous cements, 5-12 min; 18 ZnO cements, 9-78 min; 15 Cu cements, 8-25 min;  $t = 20^\circ\text{C}$ . For influence of mixing temperature see Fig. 1, Curve I, a siliceous cement and Curves II and III, ZnO cements.

## Heat of Setting

No calorimetric data available. For temperature rise on setting *v.* (2).

## LITERATURE

(For a key to the periodicals see end of volume)

- (1) Poetschke, 45, 8: 302; 16. (2) Poetschke, 45, 15: 339; 23.

## SOLID FUELS

S. W. PARR

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## 1. CLASSIFICATION

For the purpose of displaying typical values of their properties and compositions, solid fuels will be assigned to classes on the basis of two characteristics which will be called unit-heat-value (*UHV*) and unit-volatile-matter (*UVM*), respectively, and which are defined by the following equations (17, 21).

$$UHV = \frac{H - 5000S}{F} \text{ BTU/lb} = \frac{H - 2778S}{F} \text{ g-cal/g}, \quad (1)$$

where *H* is the total calorific value of the fuel (BTU/lb., g-cal/g, respectively); and

$$UVM = 100 \left( \frac{V - (0.08 + 0.4S)}{F} \right) \%, \quad (2)$$

where *V* = the volatile matter per unit mass of fuel.

In both equations the factor,  $F = 1 - (W + 1.08A + 0.55S)$ , where *W*, *A* and *S* are, respectively, the water, ash and sulfur content of the unit mass of fuel as determined by chemical analysis.

The numerical factors in equations (1) and (2) are such that the quantities *UHV* and *UVM* represent, respectively, the heating value and the volatile matter per unit mass of fuel-substance contained in the solid fuel; see also (17, 21).

By means of these two characteristics, every solid fuel can be represented as a point on a plane and the location of this point with respect to the areas which have been selected for delimiting the various classes of solid fuels, identifies the class to which the fuel belongs and its relative location in that class. This is illustrated by the diagram in Fig. 1. The circles represent the loci of certain selected samples, representative of each class, and whose compositions are shown in Table A. The crosses represent the loci of a series of coals corresponding to the composition averages of Tables 2-10.

Another method for classifying coals, based upon limits for carbon, hydrogen, oxygen plus nitrogen, and volatile matter has been proposed by Seyler (27, 28, 29, 30). The classes which he proposes are, however, in close agreement with those defined in Fig. 1 [cf. (24)] and a comparison of the proposed nomenclatures is shown in the following table. All proposed nomenclatures are provisional, since no agreement has as yet been reached.

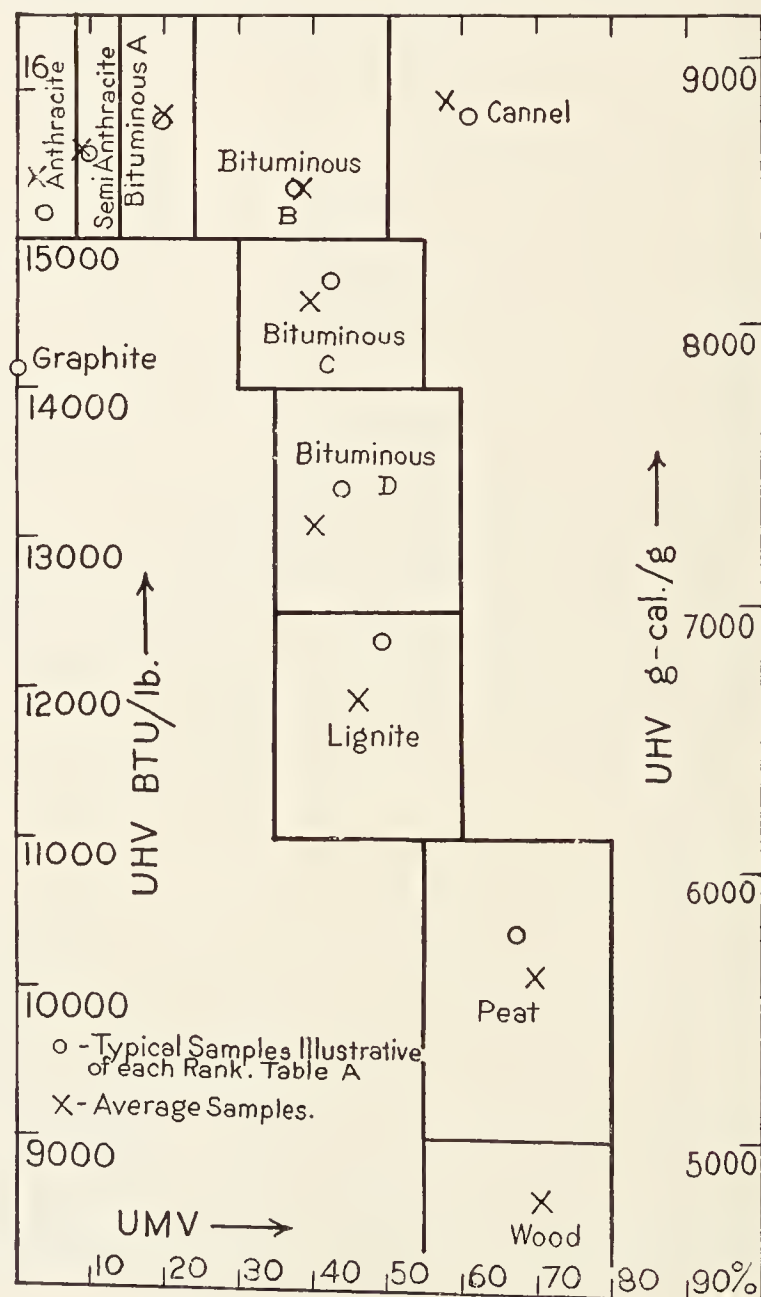


FIG. 1.—Classification of solid fuels.



TABLE A.—PERCENTAGE COMPOSITION OF TYPE SAMPLES OF SOLID FUELS

Type	State and county	Proximate				Ultimate					Air-dry loss	g-cal/g	BTU/lb	UHV BTU	UVM
		Vola-tiles	Fixed C	H <sub>2</sub> O	Ash	S	H	C	N	O					
Anthracite.....	Schuylkill Co., Pa.	3.27	84.28	3.33	9.12	0.60	2.71	81.35	0.79	2.10	2.6	7 417	13 351	15 410	2.63
Semi-anthracite.....	Sullivan Co., Pa.	8.59	78.08	3.16	10.17	0.67	3.12	79.49	1.10	2.29	2.6	7 431	13 376	15 610	8.79
Bituminous A.....	McDowell Co., W. Va.	18.68	72.04	2.80	6.48	0.70	4.26	81.75	1.35	2.66	0.0	7 923	14 261	15 820	19.89
Bituminous B.....	Mingo Co., W. Va.	34.37	56.85	2.44	6.34	0.95	4.96	77.90	1.54	5.87	1.0	7 721	13 898	15 340	38.20
Bituminous C.....	Williamson Co., Ill.	32.92	48.30	9.94	8.84	1.28	4.24	66.18	1.46	8.06	4.4	6 508	11 714	14 590	39.71
Bituminous D.....	Moffat Co., Colo.	30.41	44.36	18.94	6.29	0.64	3.60	57.47	0.82	12.23	6.1	5 401	9 722	13 080	40.19
Lignite.....	El Paso Co., Colo.	24.44	27.27	34.40	13.89	0.14	2.64	35.94	0.66	12.33	26.4	3 364	6 055	11 930	46.20
Peat.....	Fond du Lac Co., Wis.	13.37	5.70	76.94	3.99	0.17	1.02	10.87	0.68	6.33	73.8	1 044	1 879	10 100	69.58
Wood.....	Air-dry	61.87	26.50	11.36	0.27		5.35	44.13	0.08	38.83		4 242	7 635	8 650	70.05
Cannel.....	Johnson Co., Ky.	50.64	36.70	2.20	10.46	0.99	6.33	72.01	1.17	6.84	1.3	7 638	13 748	15 920	57.55

TABLE B.—PERCENTAGE COMPOSITION OF TYPICAL WORLD COALS

Country and location	H <sub>2</sub> O	Vola-tiles	Fixed C	Ash	S	BTU/lb.	g-cal/g	UHV BTU	UVM
England, Durham, Horden.....	1.50	34.68	59.15	3.80	0.87	13 330	7 420	14 140	36.20
England, Leicester, Nailstone.....	13.22	30.99	50.52	5.27	1.25	13 170	7 320	16 290	38.05
England, Yorkshire, Dearne Valley.....	8.44	37.01	51.19	2.00	1.36	13 397	7 440	15 020	40.90
Scotland, Ayrshire, Caprington.....	6.86	36.65	51.56	4.14	0.79	12 422	6 905	14 010	40.80
Scotland, Edinburgh, Newbattle.....	9.87	31.32	55.02	3.43	0.36	12 915	7 200	14 930	63.40
Scotland, Lanark, Coalburn.....	7.50	31.56	56.68	4.04	0.22	13 690	7 610	15 540	35.25
Wales, Cardiff.....	1.04	17.17	76.53	5.26	0.86	14 479	8 045	15 540	17.68
Wales, Neath.....	1.83	7.47	86.82	3.88	0.79	14 574	8 090	15 520	7.32
Wales, Port Talbot.....	2.41	11.65	70.49	15.45	1.01	13 124	7 310	16 260	12.48
Germany, Westphalia, Ruhr.....	0.30	6.00	87.60	6.10	0.90	14 080	7 822	15 100	5.90
Germany, Westphalia, Ruhr.....	0.80	12.40	79.50	7.30	1.40	13 940	7 745	15 300	12.42
Germany, Westphalia, Ruhr.....	2.60	29.20	64.20	4.00	0.80	13 760	7 644	14 810	30.80
Germany, Saar.....	1.73	33.16	57.54	7.57	0.94	13 896	7 720	15 450	35.90
Germany, Saxony.....	8.17	35.93	53.75	2.15	0.76	12 728	7 071	14 230	39.80
Germany, Saxony, brown coal.....	14.42	44.63	33.85	7.10	1.17	8 872	4 929	11 400	56.50
Bulgaria, Boronschitzta.....	0.72	36.05	56.43	5.30	3.01	12 690	7 050	13 650	37.50
Japan, Joban.....	12.24	40.61	36.11	11.04	1.02	9 759	5 423	12 900	52.20
Japan, Chihuko.....	4.21	42.92	45.71	7.33	0.68	12 965	7 205	14 780	48.10
S. Africa, Middleburg.....	2.57	29.16	57.68	10.59	0.42	12 392	6 885	14 425	32.45
S. Africa, Natal.....	1.28	23.70	67.06	7.96	1.24	13 720	7 622	15 271	25.01
Australia, New South Wales.....	1.89	41.35	50.51	6.25	1.01	12 760	7 090	14 000	41.50
Australia, New Zealand.....	0.70	16.68	77.67	4.95	0.30	14 915	8 286	15 890	17.20
Canada, Alberta, Crows Nest.....	2.10	23.10	58.60	16.20	0.50	12 400	6 888	15 420	26.95
Canada, New Brunswick, Minto.....	1.20	31.70	53.80	13.30	6.60	13 020	7 240	15 690	37.90
Canada, Nova Scotia, Sidney Field.....	3.70	35.00	54.20	7.02	2.79	13 150	7 306	14 910	37.40

TABLE 1.—CLASSIFICATION OF COALS

Type No.	Table No.	Type	Name		
		Parr	Common	Seyler	
1	2	Anthracite	Anthracite	Anthracite	
2	3	Semi-anthracite	Semi-anthracite	Carbonaceous	
3	4	Bituminous A	Semi-bituminous or low volatile	Meta-bituminous (short flame)	
4	5	Bituminous B	Bituminous (eastern field)	Ortho-bituminous (true bituminous)	
5	6	Bituminous C	Bituminous (mid-continental field)	Para-bituminous (long flame)	
6	7	Bituminous D	Lignite, black, or sub-bituminous	Lignitous	
7	8	Lignite	Lignite, brown	Lignitous	

TABLE 1.—CLASSIFICATION OF COALS.—(Continued)

Type No.	Table No.	Type	Name		
		Parr	Common	Seyler	
8	9	Peat			
9		Wood			
10	10	Cannel			
11	11	Coke			
12		Semi-coke			
13		Briquettes			
14		Pulverized			

## PERCENTAGE COMPOSITION OF U. S. COALS

TABLE 2.—TYPE 1, ANTHRACITE

State, county, and seam	H <sub>2</sub> O	Vol.*	Fixed C	Ash	S	BTU/lb.	g-cal/g	UHV BTU	UVM
Colo., Gunnison.....	2.70	3.32	88.15	5.83	0.80	14 099	7 840	15 510	2.79
Colo., Gunnison.....	4.86	6.96	81.87	6.31	0.81	13 468	7 475	15 300	6.98
N. Mex., Santa Fe.....	5.70	2.18	86.13	5.93	0.69	13 286	7 375	15 130	1.63
N. Mex., Santa Fe.....	7.55	7.25	75.88	9.32	0.76	12 101	6 725	14 720	7.55
Pa., Schuylkill.....	2.76	2.48	82.07	12.69	0.54	12 577	6 970	15 075	1.51
Pa., Schuylkill.....	2.80	1.16	88.21	7.83	0.89	13 298	7 380	15 010	0.24
Pa., Schuylkill.....	2.30	1.54	82.77	13.39	1.05	12 523	6 955	15 080	0.08
Pa., Schuylkill.....	3.33	3.27	84.28	9.12	0.60	13 351	7 415	15 410	2.66
Pa., Luzerne.....	1.31	5.68	85.87	7.14	0.42	13 777	7 645	15 150	5.44
Pa., Luzerne.....	2.19	5.67	86.24	5.90	0.57	13 828	7 680	15 120	5.77
Pa., Lackawanna.....	3.43	6.79	78.25	11.53	0.46	12 782	7 097	15 200	6.75
Utah, Washington, No. 6.....	8.21	4.41	58.02	29.36	2.28	8 908	4 948	14 920	2.05
Wash., Lewis, Primrose.....	7.40	4.80	52.00	35.80	0.74	8 200	4 555	15 530	1.20
Wash., Whatcom, Puget.....	4.40	7.40	76.00	12.23	0.96	12 590	6 998	15 360	7.37
Average.....	4.21	4.49	78.98	12.31	0.82	12 485	6 935	15 170	3.86

\* Vol. = volatile matter.

TABLE 3.—TYPE 2, SEMI-ANTHRACITE

State, county, and seam	H <sub>2</sub> O	Vol.	Fixed C	Ash	S	BTU/lb.	g-cal/g	UHV BTU	UVM
Ark., Pope, Hartshorne.....	2.07	9.81	78.82	9.3	1.74	13 702	7 620	15 690	9.65
Col., Gunnison, Crested Butte.....	1.94	9.22	80.34	8.50	0.85	13 740	7 640	15 485	9.28
Pa., Sullivan.....	3.38	8.47	76.65	11.50	0.63	13 156	7 305	15 660	8.71
Pa., Sullivan.....	3.47	9.28	76.10	11.15	0.78	13 216	7 345	15 685	9.60
Pa., Sullivan.....	3.40	9.34	75.58	11.68	0.81	13 120	7 292	15 630	9.67
Pa., Sullivan.....	3.16	8.59	78.08	10.17	0.67	13 376	7 430	15 610	8.58
Utah, Washington, No. 4.....	7.02	10.30	60.61	22.07	4.06	10 408	5 787	15 290	10.35
Va., Montgomery, large.....	2.5	12.40	67.50	17.60	0.51	12 360	6 860	15 770	13.81
Wash., Lewis, Primrose.....	3.60	8.40	59.60	28.40	0.66	10 050	5 578	15 330	9.00
Average.....	3.39	9.53	72.58	14.48	1.19	12 570	6 980	15 580	9.83

TABLE 4.—TYPE 3, BITUMINOUS A

State, county, and seam	H <sub>2</sub> O	Vol.	Fixed C	Ash	S	BTU/lb.	g-cal/g	UHV BTU	UVM
Ark., Sebastian, Hartshorne.....	1.7	16.91	73.03	8.36	1.23	13 840	7 688	15 510	17.70
Md., Allegheny, Pittsburgh.....	2.43	19.02	71.19	7.36	1.04	14 087	7 822	15 730	20.12
Md., Garrett, Freeport.....	2.39	16.41	71.82	9.38	2.01	13 707	7 618	15 770	17.23
Okla., Haskell, Hartshorne.....	2.37	19.26	69.54	8.83	1.03	13 840	7 690	15 740	20.72
Pa., Cambria, Lower Freeport.....	2.87	21.44	69.23	6.46	1.52	14 177	7 875	15 690	22.74
Pa., Clearfield, Lower Kittanning.....	3.20	21.00	69.30	6.50	0.69	14 060	7 820	15 700	22.60
Pa., Somerset, Pittsburgh.....	3.04	19.59	70.33	7.04	0.74	14 175	8 045	15 920	21.10
Pa., Huntington, Fulton.....	1.65	17.48	72.26	8.61	1.55	14 076	7 825	15 850	18.31
Va., Tazewell, Pocahontas No. 3.....	2.85	21.25	71.43	4.47	0.59	14 620	8 128	15 830	22.40
W. Va., Fayette, Sewell.....	3.58	21.07	72.75	2.60	0.64	14 751	8 190	15 790	22.20
W. Va., McDowell, Pocahontas No. 4.....	2.87	14.91	78.39	3.83	0.81	14 809	8 235	15 920	14.33
W. Va., McDowell, Pocahontas No. 3.....	2.03	18.51	75.54	3.92	0.49	14 812	8 240	15 840	19.29
Average.....	2.58	18.90	72.06	6.45	1.02	14 246	7 915	15 795	19.87

TABLE 5.—TYPE 4, BITUMINOUS B

State, county, and seam	H <sub>2</sub> O	Vol.	Fixed C	Ash	S	BTU/lb.	g-cal/g	UHV BTU	UVM
Ala., St. Clair, Harkness.....	2.28	33.07	54.33	10.02	1.76	13 333	7 405	15 410	36.77
Ala., Tuscaloosa, Jagger.....	1.60	24.98	68.55	4.87	0.51	14 697	8 155	15 800	26.28
Ala., Jefferson, Pratt.....	1.05	31.70	62.15	6.15	1.38	14 377	7 980	15 610	33.45
Ky., Letcher, Elkhorn.....	2.91	36.33	57.53	3.23	0.53	14 170	7 875	15 160	38.44
Ky., Harlan, Harlan.....	2.80	37.00	55.90	4.30	1.10	13 950	7 748	15 120	39.42
Ky., Whitley, Jellico.....	5.02	36.08	54.47	4.43	0.92	13 608	7 555	15 110	39.40



TABLE 5.—TYPE 4, BITUMINOUS B.—(Continued)

State, county, and seam	H <sub>2</sub> O	Vol.	Fixed C	Ash	S	BTU/lb.	g-cal/g	UHV BTU	UVM
Ohio, Jefferson, Lower Freeport.....	3.50	37.98	51.08	7.44	3.09	13 286	7 377	15 140	41.78
Ohio, Tuscarawas, Lower Kittanning.....	4.49	40.55	47.43	7.53	2.93	12 958	7 200	14 960	45.25
Ohio, Belmont, Meigs Creek.....	4.34	38.95	45.50	11.21	3.65	12 402	6 895	14 990	49.85
Ohio, Guernsey, Pittsburgh.....	4.36	41.14	45.76	8.74	4.85	12 710	7 058	14 910	46.05
Pa., Washington, Washington.....	4.45	33.53	49.51	12.51	3.04	12 242	6 800	15 060	39.00
Pa., Westmoreland, Pittsburgh.....	2.73	30.34	57.80	9.13	1.33	13 613	7 556	15 610	33.47
Pa., Cambria, Upper Freeport.....	2.73	26.04	65.05	6.18	1.39	14 269	7 925	15 800	27.82
Pa., Jefferson, Lower Freeport.....	1.86	34.63	53.23	10.28	2.91	13 151	7 300	15 220	38.00
Va., Russell, Upper Banner.....	2.07	35.90	57.70	5.33	0.57	14 335	7 952	15 590	38.40
Va., Wise, Imboden.....	2.16	33.10	58.27	6.47	0.68	13 994	7 756	15 410	35.70
W. Va., Marion, Pittsburgh.....	1.75	36.77	55.14	6.34	0.90	14 107	7 845	15 490	39.50
W. Va., Randolph, Lower Kittanning.....	1.45	28.97	59.48	10.10	0.98	13 718	7 620	15 700	31.84
W. Va., Kanawha, Coalburg.....	3.44	35.20	53.08	8.28	0.70	13 304	7 396	15 220	39.50
W. Va., Kanawha, No. 2 gas.....	2.66	33.30	59.60	4.44	1.14	14 368	7 975	15 590	35.38
Average.....	2.85	34.27	55.59	7.35	1.71	13 630	7 580	15 330	37.40

TABLE 6.—TYPE 5, BITUMINOUS C

State, county, and seam	H <sub>2</sub> O	Vol.	Fixed C	Ash	S	BTU/lb.	g-cal/g	UHV BTU	UVM
Ill., Vermilion, No. 7.....	13.16	37.95	39.02	9.85	4.33	11 110	6 175	14 760	46.60
Ill., Williamson, No. 6.....	9.44	32.99	48.95	8.62	0.93	11 858	6 594	14 470	39.10
Ill., Saline, No. 5.....	5.56	34.41	51.31	8.72	2.87	12 643	7 038	14 990	39.04
Ill., Sangamon, No. 5.....	13.09	36.51	41.14	9.26	3.77	10 935	6 075	14 360	45.70
Ill., Bureau, No. 2.....	16.27	38.35	38.00	7.38	2.93	10 883	6 045	14 480	49.25
Ill., Mereer, No. 1.....	15.58	39.17	35.80	9.45	4.69	10 673	5 927	14 570	50.98
Ind., Sullivan, No. 6.....	14.86	31.65	46.14	7.35	2.16	11 324	6 300	14 620	39.78
Ind., Vigo, Minshall.....	13.10	36.83	41.73	8.34	2.60	11 484	6 378	14 860	49.20
Iowa, Lucas.....	15.39	30.49	41.49	12.63	3.19	10 242	5 690	14 560	40.70
Iowa, Marion.....	14.21	33.17	37.40	15.22	4.66	10 019	5 573	14 640	45.00
Ky., Webster, No. 12.....	5.58	35.04	51.32	8.06	1.59	12 755	7 095	14 950	39.68
Ky., Hopkins, No. 14.....	8.85	35.29	47.51	8.35	2.79	11 921	6 625	14 595	41.51
Ky., Union, No. 9.....	4.37	36.27	47.67	11.69	3.58	12 325	6 852	14 985	41.80
Kans., Cherokee, Cherokee.....	5.11	32.60	53.39	8.90	4.34	12 926	7 185	15 320	36.40
Kans., Osage, Osage.....	5.10	36.85	48.10	9.95	5.02	10 930	6 070	14 970	47.58
Mo., Henry, Jordan.....	10.10	34.83	41.76	13.31	4.32	11 158	6 200	14 950	43.78
Okla., Pittsburg, Lower Hartshorne.....	4.33	35.51	54.04	6.12	0.84	13 574	7 548	15 260	39.15
Okla., Okmulgee, Henryetta.....	8.87	34.82	47.68	8.63	1.62	12 096	6 720	14 880	41.45
Average.....	10.16	35.15	45.13	9.54	3.12	11 603	6 460	14 720	42.55

TABLE 7.—TYPE 6, BITUMINOUS D

State, county, and seam	H <sub>2</sub> O	Vol.	Fixed C	Ash	S	BTU/lb.	g-cal/g	UHV BTU	UVM
Colo., Boulder.....	19.14	33.44	42.07	5.35	0.27	10 017	5 570	13 380	43.90
Colo., El Paso.....	19.23	32.34	41.41	7.02	0.45	9 306	5 170	12 780	43.43
Colo., Moffat.....	22.10	31.61	41.95	4.34	0.72	9 297	5 165	12 710	42.50
Colo., Weld.....	22.20	39.23	33.12	5.45	0.33	9 578	5 320	13 310	53.90
Mont., Choutou.....	16.83	27.89	43.78	11.50	1.19	9 563	5 315	13 575	37.69
Mont., Musselshell, Homestead.....	18.14	27.22	50.49	4.15	0.88	10 420	5 795	13 540	33.20
Mont., Park, Maxey.....	16.33	30.12	40.05	13.50	0.41	9 247	5 130	13 400	40.51
N. Mex., McKinley.....	13.50	37.75	42.51	6.24	0.36	11 140	6 195	13 990	46.65
N. Mex., San Juan.....	19.01	32.43	43.15	5.41	0.92	10 193	5 670	13 575	42.30
Utah, Summit.....	17.08	36.94	41.24	4.74	1.53	10 179	5 663	13 140	46.72
Wash., King, No. 1.....	16.45	34.63	36.38	12.54	0.38	9 581	5 335	13 690	47.96
Wash., Lewis.....	20.50	33.50	33.70	12.31	1.28	8 690	4 820	13 170	48.80
Wash., Thurston.....	21.00	33.10	36.70	9.20	0.42	8 910	4 950	12 910	46.78
Wyo., Carbon.....	13.62	34.55	43.14	8.69	1.44	10 339	5 745	13 480	43.60
Wyo., Hot Springs, Gebo.....	17.87	31.26	43.48	7.39	0.66	10 062	5 594	13 780	41.75
Wyo., Sheridan.....	22.57	32.53	40.36	4.55	0.30	9 218	5 123	12 710	44.34
Wyo., Sweetwater.....	15.71	33.50	48.40	2.39	0.93	11 144	6 185	13 670	40.55
Average.....	18.31	33.06	41.29	7.34	0.73	9 818	5 450	13 330	43.80

TABLE 8.—TYPE 7, LIGNITE

State, county, and seam	H <sub>2</sub> O	Vol.	Fixed C	Ash	S	BTU/lb.	g-cal/g	UHV BTU	UVM
Ark., Ouachita, Lignite.....	39.50	25.35	22.57	12.58	0.53	5 877	3 262	12 550	51.75
Colo., Adams.....	35.00	27.39	30.23	7.38	0.31	6 982	3 880	12 230	46.90
Colo., Elbert, Laramie.....	33.10	25.60	25.60	15.66	0.44	6 150	3 420	12 300	48.60
Colo., El Paso.....	34.40	24.44	27.27	13.89	0.14	6 055	3 362	11 930	46.20
N. D., Adams, Haynes.....	32.65	30.57	28.49	8.29	1.53	7 357	4 080	12 640	50.80
N. D., Billings.....	43.51	25.23	24.87	6.39	1.04	5 814	3 230	11 700	49.40
N. D., Bowman.....	34.80	31.09	25.98	8.13	0.66	6 916	3 840	12 270	53.80
N. D., Morton.....	38.52	27.60	26.60	7.28	1.31	6 703	3 722	12 530	50.15
N. D., Stark.....	42.06	24.55	25.73	7.66	1.13	6 158	3 420	12 440	47.80
N. D., Ward.....	36.93	24.92	27.72	10.43	0.22	6 010	3 340	11 610	46.40
N. D., Williams.....	42.91	26.81	24.98	5.30	0.71	6 232	3 460	12 160	49.30
Tex., Milam.....	35.30	26.22	29.58	8.90	0.76	6 898	3 830	12 540	46.15
Tex., Wood.....	33.71	29.25	29.76	7.28	0.53	7 348	4 075	12 600	50.70
Average.....	37.11	26.85	26.87	9.17	0.72	6 500	3 640	12 300	49.20

TABLE 9.—TYPE 8, PEAT

State, county, and seam	H <sub>2</sub> O	Vol.	Fixed C	Ash	S	BTU/lb.	g-cal/g	UHV BTU	UVM
Conn., Fairfield.....	90.31	3.79	1.27	4.63	0.08	511	284	10 900	82.68
Conn., New London.....	85.66	8.52	4.54	1.28	0.10	1 382	769	9 900	67.40
Fla., Duval.....	73.10	14.00	8.05	4.85	1.06	2 309	1 282	10 695	61.80
Fla., Lake.....	82.12	11.75	5.72	0.41	0.05	1 886	1 047	10 820	67.20
Fla., Putnam.....	80.78	9.72	6.32	3.18	0.40	1 661	924	10 520	59.80
Me., Aroostook.....	86.18	8.27	3.98	1.57	0.10	1 294	719	10 680	67.00
Me., Knox.....	90.82	6.07	2.73	0.38	0.02	819	455	9 350	68.80
Me., Washington.....	85.22	8.86	4.72	1.20	0.07	1 444	802	10 710	64.90
Mich., Kalamazoo.....	66.91	19.04	9.29	4.76	0.09	3 024	1 670	10 825	66.66
N. Y., Oswego.....	54.66	29.15	12.44	3.75	0.17	4 104	2 278	9 950	69.77
Wis., Dane.....	71.33	16.01	6.75	5.91	0.12	2 187	1 216	9 820	69.61
Wis., Langlade.....	80.24	9.21	4.17	6.38	0.13	1 256	697	9 780	67.40
Wis., Marinette.....	76.36	10.78	4.66	8.20	0.16	1 498	832	9 930	68.30
Average.....	78.74	11.93	5.74	3.57	0.19	1 798	999	10 370	66.80

TABLE 10.—TYPE 10, CANNEL COAL

State, county, and seam	H <sub>2</sub> O	Vol.	Fixed C	Ash	S	BTU/lb.	g-cal/g	UHV BTU	UVM
Ind., Perry.....	1.47	49.08	26.35	23.10	1.50	10 850	6 030	14 810	64.0
Ky., Johnson, Cannel.....	2.36	48.40	38.75	10.49	1.20	13 770	7 645	16 010	54.9
Ky., Johnson, Lesley Cannel.....	1.7	50.7	38.2	9.3	1.02	14 250	7 915	16 190	56.5
Tenn., Campbell, Blue Gem.....	1.50	45.10	34.10	19.30	1.16	12 340	6 855	15 930	55.8
Tex., Webb, Cannel.....	3.98	48.87	34.91	12.24	1.96	12 227	6 790	14 830	57.65
Wash., Lewis, Cannel No. 3.....	7.88	61.57	15.11	15.44	0.29	11 920	6 630	15 810	79.26
W. Va., Boone, Chilton.....	0.52	50.92	35.82	12.74	1.10	13 830	7 680	16 200	57.95
W. Va., Boone, Cedar Grove.....	0.43	56.99	33.90	8.68	1.85	15 000	8 335	16 720	62.30
Average.....	2.48	51.45	32.14	13.91	1.26	13 023	7 230	15 820	60.85

TABLE 11.—ANALYSIS AND PHYSICAL PROPERTIES OF COKE AND WOOD CHARCOAL

Type	H <sub>2</sub> O	Vol.	Fixed C	Ash	H	C	N	O	S	BTU/lb.	% porosity	lb./ft. <sup>3</sup>
Jones and Laughlin.....	0.2	1.5	85.9	12.4	0.6	84.9	1.0	0.2	0.9	12 400	48.2	31
Continental No. 1.....	0.1	0.9	88.1	10.9	0.7	86.3	1.3	0.0	0.8	12 810	50.3	29
Leisenring No. 1.....	0.1	0.5	88.0	11.4	0.4	85.9	1.1	0.4	0.8	12 510	46.5	30.5
Wilkenson.....	0.2	0.5	80.3	19.0	0.4	78.9	1.4	0.0	0.5	11 690	54.1	27
Wood charcoal.....	3.2	20.0	72.8	4.0	3.7	78.7	0.4	13.1	0.1	12 920	63.2	17



### CALORIFIC VALUE

The values characteristic of the different classes of solid fuels are evident from Fig. 1. The calorific value of a solid fuel of the fossil fuel type may be computed (1 to 2%) by means of the Du Long formula,  $H = 8080C + 34\,500 \left( H - \frac{O}{H} \right) + 2250S$ , g-cal, where  $C$  = total carbon,  $\left( H - \frac{O}{H} \right)$  = combustible hydrogen, and  $S$  = sulfur; cf. (34).

It may also be computed from equation (1) since the value of UHV is constant for a given mine or region and needs to be determined only once. For standard calorimetric methods, v. (5).

### SULFUR CONTENT

For methods of differentiating between organic and inorganic  $S$ , v. (23). Distribution of the different forms, v. (19, 39, 40).

### ASH FUSIBILITY

Methods (14, 26). Results for 2000 coals (26). Fusibility of coal ash by states and seams (41). Bibliography (7); see also (8, 25). Values range from 1040° to 1700°C.

### Oxidation of Dry Coal

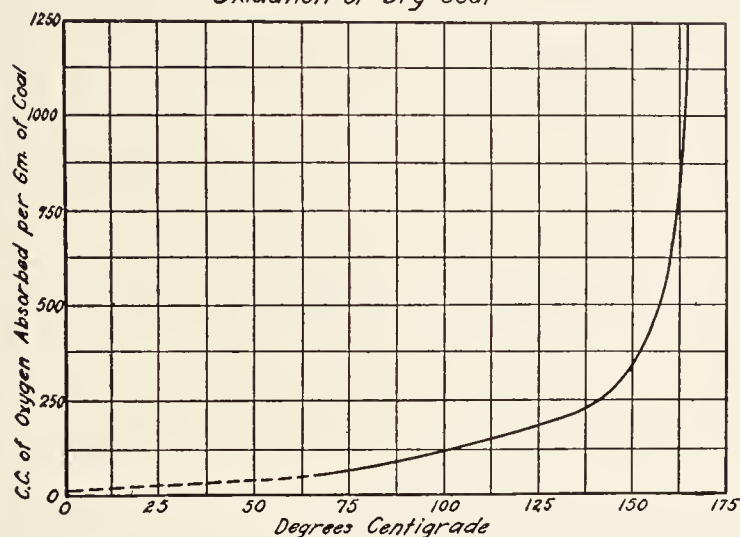


FIG. 2.—(Courtesy Industrial and Engineering Chemistry.)

### DENSITY

True density, g/cm<sup>3</sup>; anthracite, 1.4–1.8; bituminous, 1.2–1.5; lignite, 1.1–1.4 (15). Coke, 1.45–2.0 (35).

BULK DENSITY IN BIN OR PILE, ±10 TO 15% (9)  
Anthracite

Size	lb./ft. <sup>3</sup>	kg/m <sup>3</sup>
Buckwheat.....	55	888
Pea.....	54	870
Chestnut.....	56	891
Range.....	56	899
Egg.....	56	891
Furnace.....	54	866
Bituminous		
Screenings.....	51–52	820–830
Lump.....	48	774
Sub-bituminous.....		
Lump.....	45–46	720–737

Additional literature: (3, 11, 12, 42).

### POROSITY

Methods (3). Coal—no data. Coke—29–59% (3); v. Table 11.

### SPECIFIC HEAT

0.26 to 0.37 g-cal/g (22).

### SPONTANEOUS COMBUSTION, WEATHERING AND DETERIORATION

Absorption of oxygen by powdered bituminous coal: Fig. 2 (18). Effect of storage on calorific power: Fig. 3 (20).

### COKING BEHAVIOR

See (6, 10, 13, 14, 16, 32, 33, 37).

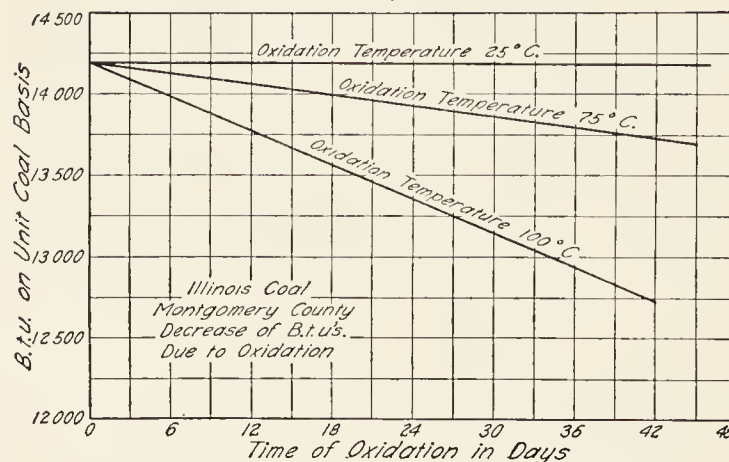


FIG. 3.—(Courtesy Industrial and Engineering Chemistry.)

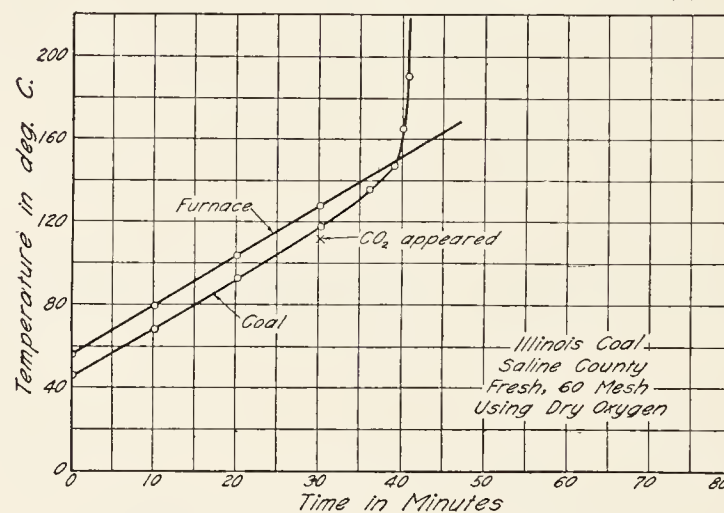


FIG. 4.—(Courtesy Industrial and Engineering Chemistry.)

### IGNITION TEMPERATURES

The ignition temperature of a mass of coal is the temperature at which oxidation within the mass proceeds autogenously under the conditions of the experiment. Curves showing typical progress of heating within and without a 10 g sample of bituminous coal are shown in Figs. 4 and 5 (38). The following table (36) gives the ignition temperatures of various types of coal, using dry oxygen and 60 mesh "as-received" coal.

Type No.	CO <sub>2</sub> evolved at, °C	Ignition temp., °C
5	73	153
5	70	152
5	74	169
5	75	147
5	70	153
5	65	157
5	70	157
5	81	152
5	75	159
5	80	149
4	70	170
5	75	171
1	70	242
4	75	171
4	75	194
4	78	213
4	85	185

## COMBUSTIBILITY OF COKE

A combustibility test is designed to show "the speed at which the carbon molecules in the coke combine with oxygen under given conditions" and is especially important in determining the value of a blast furnace coke. For method and results, *v.* (31).

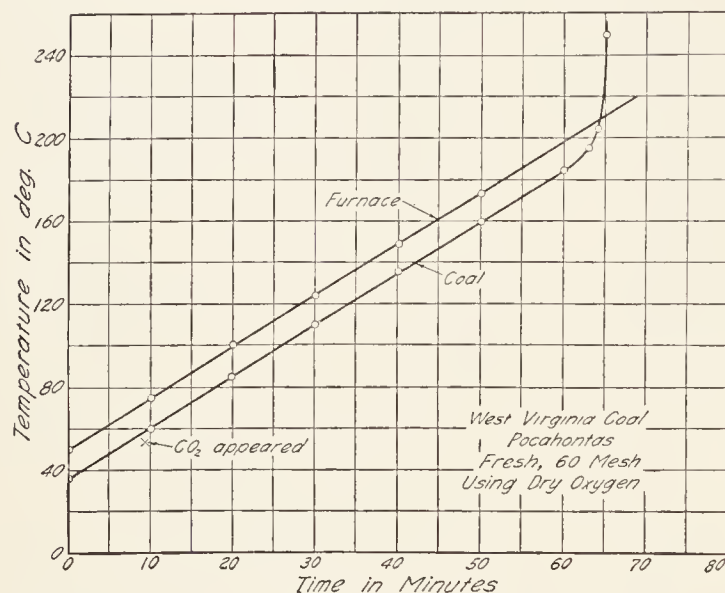


Fig. 5.—(Courtesy Industrial and Engineering Chemistry.)

## LITERATURE

(For a key to the periodicals see end of volume)

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## PETROLEUMS, PETROLEUM PRODUCTS AND COMMERCIAL OILS OF MINERAL ORIGIN

E. H. LESLIE AND J. C. GENIESSE

With acknowledgments to E. B. Badger and Sons Company of Boston for valued clerical assistance

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## COMPOSITION AND DENSITY OF CRUDE PETROLEUMS

## North America

## CANADA

Low boiling constituents are of the  $C_nH_{2n+2}$  series up to  $C_{10}$ . The  $C_nH_{2n}$  series starts at  $C_{11}$  and includes both straight-chain olefins and saturated naphthenes. The series poorer in hydrogen occur in the high boiling fractions. More aromatics present than in Pennsylvania or Ohio oils. Sulfur as thiophanes,  $C_nH_{2n}S$  (121, 127, 135, 136, 172).

Source	Sp. gr. at t°C	% C	% H	% N	% O	% S	Lit.
Bothwell.....	0.857	84.3	13.4	2.3			(53.1)
Cherryvale.....		85.4	13.1			0.37	(53.1)
Great Manitoulin Is...	0.828	83.1	14.3	2.6			(53.1)
Humboldt.....		85.6	12.4			0.37	(53.1)
Humboldt.....		85.3	11.8			0.15	(53.1)
Oil Springs.....	0.844	83.6	13.4	0.18		0.6	(53.1)
Petrolia.....	0.862	83.9	13.4	0.16		1.01	(53.1)
Petrolia.....	0.870	84.5	13.5	2.0			(53.1)
Petrolia (169 m).....	0.844	82.7	13.5	3.8			(53.1)

## UNITED STATES

Source	Sp. gr. at t°C	% C	% H	% N	% O	% S	Lit.
<i>California.</i> —Proportion of distillates below 225°C small to moderate and composed of methylenes similar in B. P. and sp. gr. to those in Russian oil, except for the compounds $C_{11}H_{22}$ , $C_{12}H_{24}$ and $C_{13}H_{26}$ . Proportion of aromatics large. Members of the $C_nH_{2n+2}$ series absent (133). Organic bases mainly mixture of alkylated quinolines with small side chains (139). Oxygen usually as naphthenic acids with some phenolic compounds. Sulfur as $C_nH_{2n}S$ .							
Adams Canyon...	0.921	30		1.46		0.90	(113)
Bardsdale.....	0.892	20	84.2	12.2	1.25	1.5	(113)
Coalinga*.....	0.951	15	86.4	11.7	1.14	0.60	(53.1)
Kern River.....	0.967	15	86.4	11.3	0.74	0.89	(53.1)
McKittrick.....			86.1	11.5		0.87	(113)
McKittrick.....	0.960	15	86.5	11.4	0.58	0.74	(53.1)
Midway.....	0.958	15	86.6	11.6	0.74	0.82	(53.1)
Puente†.....	0.892	20	85.0	12.0	1.20	0.80	(113)
Summerland....	0.985		86.3	11.7	1.25	0.84	(125)

## California.—(Continued)

Source	Sp. gr. at t°C		% C	% H	% N	% O	% S	Lit.
Sunset.....	0.971	15	85.6	11.4	0.84		1.09	(53.1)
Torrey.....	0.884	20	86.0	12.5	1.15		0.5	(113)
Ventura.....			86.9	11.8	1.11			(113)
Ventura County	0.912		84.0	12.7	1.7	1.2	0.4	(15.1)
San Joaquin Val- ley.....	0.961	15.5	86.3	11.4	0.81		0.82	(7)
Fresno region...	0.842	20	86.2	13.1			0.21	(53.1)

\* Contains hexane, benzene, toluene, xylene and 7 hydrocarbons of the  $C_nH_{2n}$  series (123).

† Contains naphthenes  $C_7H_{14}$ ,  $C_8H_{16}$ ,  $C_{10}H_{20}$ ,  $C_{11}H_{22}$ . Paraffins above M. P. 95° absent. A considerable proportion of aromatics in distillate. Large proportion of naphthene in 221°–222° distillate.

*Kansas.*—Mixture of paraffin- and naphthene-base crude (172).

Chanute.....		84.7	14.6	0.45		0.61	(165)
Humbolt.....	0.912	85.6	12.4			0.37	(113)
Neodesha.....		84.0	13.1	0.81	0.04	0.88	(165)
Towanda.....		84.2	13.0	0.45		1.9	(165)

*Ohio.*—Paraffin-base predominates in the east. Heptylene and many alkyl sulfides have been isolated (129, 137).

Baltimore.....	0.824	20	84.2	14.6	0.08		0.61	(53.1)
Findlay.....	0.836		84.6	13.6	0.11		0.72	(113)
Heilstone Oil Co.	0.830	20	85.8	13.8	0.023		0.63	(53.1)
Liberty (Wood)...	0.843	20	85.1	13.3	0.056		0.76	(53.1)
Liberty (Han- cock).....	0.828	20	84.2	13.4	0.35		0.68	(53.1)
Liberty (Han- cock).....	0.835	20	84.0	13.1	0.047		0.71	(53.1)
Lima.....	0.851	20	85.0	13.1	0.024		0.81	(53.1)
Lima.....			85.0	13.8			0.60	(113)
Mahone*.....	0.904		86.4	13.3	0		0.01	(128)
Mecca.....			86.3	13.1	0.23			(53.1)
Montgomery ...	0.827	20	83.9	13.2	0.054		0.37	(53.1)
Ohio.....	0.887	0	84.2	13.1	2.7			(53.1)
Ohio (Wood)...	0.819	20	84.3	13.5	0.21		0.56	(53.1)
Portage.....	0.815	20	84.4	13.4	0.13		0.68	(53.1)
St. Mary's.....	0.829	20	84.7	13.5	0.068		0.61	(53.1)
Trenton Lime- stone†.....			85.5	13.9				

\* Does not contain  $C_nH_{2n}$  or  $C_nH_{2n+2}$  series. The  $C_nH_{2n-2}$  series from  $C_{11}$  to  $C_{15}$  present in small amounts. Main constituents  $C_{16}H_{32}$ ,  $C_{17}H_{34}$  and  $C_{19}H_{38}$ . No nitrogen and only 0.01 % sulfur.

† Similar to Pennsylvania but larger proportion of aromatics. 0.2 to 0.5 % nitrogen. The  $x = 0, -2$  and  $-4$  series ( $C_nH_{2n+x}$ ) present and 13 hydrocarbons isolated (129, 120.1).

## UNITED STATES.—(Continued)

Source	Sp. gr. at t°C	% C	% H	% N	% O	% S	Lit.
<i>Oklahoma.</i> —Mixed paraffin- and asphaltic-base oils.							
Field not given		85.7	13.1	0.30		0.40	(113)
Healdton.....		85.0	12.9			0.76	(113)
<i>Oregon.</i> —Trace of aromatics (53.1).							
	0.960	20	86.1	11.9	0.87	1.19	(53.1)
<i>Pennsylvania.</i> —Typical paraffin-base oils. $C_nH_{2n+2}$ series up to $C_{35}$ . $C_nH_{2n}$ series from $C_{21}$ to $C_{26}$ . Light lubricant fraction mainly $x = -2$ series with some aromatics ( $C_nH_{2n+x}$ ); $x = -4$ and $-8$ series, and also series up to $-16$ have been identified (124, 126, 130, 172).							
Allegheny.....	0.886	0	84.9	13.7	1.4		(53.1)
Oil City.....	0.810		85.8	14.0	0.06		(113)
Oil Creek.....	0.816	0	82.0	14.8	3.2		(53.1)
Pennsylvania...			86.1	13.9		0.06	(113)
Pennsylvania...			85.8	14.0			(124)
Pa. pipe line...	0.862	15	85.5	14.2			(53.1)

## Texas

Beaumont*.....	0.91		85.7	11.0	2.61	0.7	(53.1)
Beaumont*.....	0.912		85.0	12.3	0.92	1.75	(173)

\* Sulfur as organic,  $H_2S$ , and free. Oil composed largely of bicyclic polymethylenes with small amount unsaturated hydrocarbons and their sulfur derivatives.  $x = -2$  and  $-4$  series ( $C_nH_{2n+x}$ ) present and also higher series up to  $-20$  (130, 122, 131, 174).

## Utah

			86.9	11.9	0.02	0.64	(53.1)
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## West Virginia.—Similar to Pennsylvania.

Rogers Gulch...	0.857	0	83.2	13.2	3.6		(53.1)
Mecook.....	0.897	0	83.6	12.9	3.5		(53.1)
White Oak.....	0.873	0	83.5	13.3	3.2		(53.1)
Burning Springs.....	0.841	0	84.3	14.1	1.6		(53.1)
Cumberland...			85.2	13.4	0.54		(113)

## MEXICO (31, 32)

Crude—no location given...	0.929	15	84.2	11.4	0.8	3.6	
	0.940	15	83.8	11.3	1.1	3.8	
	0.970	15	83.0	11.0	1.7	4.3	

## South America

Argentina.....	0.928	15	86.7	12.1	1.0	0.2	(31, 32)
Argentina.....	0.939	15	86.2	11.7	1.8	0.3	(31, 32)
Argentina (San Rafael)....	0.993	15	87.0	10.8	0.9	1.3	(31, 32)
(El Quemado)	0.960	15				0.5	(119)
Colombia*.....	0.948	20	85.62	11.91	0.54		(134)

\* Mainly the  $C_nH_{2n}$  series with some aromatics.

## Europe

## FRANCE

Alsace							
Pechelbronn (tar product)....	0.892	0	85.7	12.0	2.3		(169)

## FRANCE.—(Continued)

Source	Sp. gr. at t°C	% C	% H	% N	% O	% S	Lit.
Pechelbronn (wet).....	0.891	15	85.9	12.3	1.2	0.6	(31, 32)
Pechelbronn (dried).....	0.906	15	86.4	12.1	0.8	0.7	(31, 32)
Pechelbronn (dry).....	0.908	15	86.0	12.0	1.2	0.8	(31, 32)
Pechelbronn..	0.912	0	86.9	11.8	1.3		(169)
Pechelbronn..	0.908	0	85.6	9.6	4.75		(169)
Schwabweiler	0.829	0	79.5	13.6	6.9		(169)
Schwabweiler	0.861	0	86.2	13.3	0.5		(169)
Gabian.....	0.894	0	86.1	12.7	1.2		(169)

## GERMANY

Hanover.....	0.941	15	86.5	11.6	0.7	1.2	(31, 32)
Odesse.....	0.892	0	80.4	12.7	6.9		(53.1)
Oberg.....	0.944	0	84.4	11.5	4.1		(53.1)
Wietze.....	0.955	0	86.2	11.4	2.4		(53.1)

## ITALY

Pavia, Retorbido	0.979	0	86.4	12.2	1.4		(53.1)
Parma.....							
Neviano di Rossi.....	0.809	0	81.9	12.5	5.6		(53.1)
Marzolaro....	0.938	0	84.9	11.4	3.7		(53.1)
Sala Braganze	0.786	0	84.0	13.4	1.8		(53.1)
Terra di Lavoro	0.970	21	83.6	10.8			(53.1)

## POLAND

*Galicia.*  $C_nH_{2n}$  series present. No olefins but some aromatics.

East Galicia..	0.870	0	82.2	12.1	5.7		(109)
West Galicia..	0.885	0	85.3	12.6	2.1		(53.1)
Boryslaw....	0.845	15	84.4	14.3	1.34		(53.1)
Harklowa....	0.903	15	84.4	14.4	1.25		(53.1)
Justa Nowice.	0.863	15	85.3	14.4	0.20	0.11	(53.1)
Kosmacz. ....	0.867	15	85.5	13.9	0.57		(53.1)
Mraznica....	0.880	15	84.6	14.0	1.25	0.14	(53.1)
Schodniza....			85.0	14.1	0.86	0.027	(53.1)
Urycz.....	0.886	15	84.9	14.1	0.84	0.16	(53.1)
Wankowa-Brelikow....	0.854	15	85.3	14.4	0.11	0.19	(53.1)
Not definitely located.....	0.855	15	86.5	13.0	0.2	0.3	(31)
Not definitely located.....	0.871	15	86.8	12.6	0.3	0.3	(31)

## RUMANIA [cf. (66)]

Source	Sp. gr. at t°C	% C	% H	% N	% O	% S	Lit.
Crude (location not given)....	0.928	15	86.8	12.1	0.7	0.4	(31)
	0.940	15	87.2	11.3	1.1	0.4	(31)
	0.947	15	87.1	11.5	1.0	0.4	(31)
Apostolache....	0.828	15	85.5	14.1		0.19	(53.1)
Baicoi.....	0.773	15	84.1	14.8		0.09	(53.1)
Berca.....	0.801	15	85.6	14.0			(53.1)



## RUMANIA [cf. (66)].—(Continued)

Source	Sp. gr. at $t^{\circ}\text{C}$	% C	% H	% N	% O	% S	Lit.
Bisoca.....	0.877	15	85.2	13.9			(53.1)
Bustenari.....	0.842	15	86.3	13.3		0.18	(53.1)
Campani Parjol..	0.773	15	85.3	14.2		0.03	(53.1)
Campina.....	0.848	15	86.0	13.3		0.13	(53.1)
Casin.....	0.800	15	85.1	13.8		0.14	(53.1)
Comanesti.....	0.839	15	85.2	14.2			(53.1)
Dofteana Pacu- ritza.....	0.847	15	86.1	13.0		0.21	(53.1)
Glodeni.....	0.833	15	85.6	13.9			(53.1)
Gura Ocnitzei...	0.870	15	85.9	13.1			(53.1)
Lucacesti.....	0.873	15	85.9	13.3		0.28	(53.1)
Matitza-Maora...	0.878	15	85.5	13.9		0.05	(53.1)
Mosoarele.....	0.836	15	85.5	13.4			(53.1)
Pacuretzi.....	0.811	15	85.9	13.3		0.08	(53.1)
Poiana-Verbilau.	0.804	15	85.4	13.9		0.07	(53.1)
Recca.....	0.875	15	86.2	12.8		0.16	(53.1)
Sarata Monteoru	0.876	15	85.4	13.2		0.33	(53.1)
Solontzi.....	0.840	15	86.5	13.2		0.17	(53.1)
Stanesti.....	0.846	15	86.0	13.0		0.06	(53.1)
Tega.....	0.893	15	86.5	12.9			(53.1)
Tetzcani Antal...	0.791	15	85.9	13.4		0.14	(53.1)
Tetzcani Sarbi...	0.832	15	85.7	13.3			(53.1)
Tetzcani Vatra...	0.792	15	85.2	14.0			(53.1)
Wallachei (Plo- cesti).....	0.862	0	82.6	12.5	4.9		(53.1)
	0.901	0	83.0	12.2	4.8		(53.1)

## RUSSIA

Crude (no lo- cation given)	0.876	15	86.3	12.9	0.6	0.2	(31)
	0.902	15	86.1	12.8	0.9	0.2	(31)

*Baku*.—Low boiling distillate is of the  $\text{C}_n\text{H}_{2n}$  series. Aromatics 85–250°C. The high boiling distillate contains the  $x = -6$ ,  $-8$ ,  $-10$ ,  $-12$ , and  $-20$  series ( $\text{C}_n\text{H}_{2n+x}$ ) and small amount naphthenic acids (130, 142).

Baku.....	0.897		86.5	12.0		1.5	(53.1)
Baku.....	0.954		85.3	11.6		3.1	(53.1)
Benkendorff...			86.6	13.4			(53.1)
Benkendorff...			87.0	13.2			(53.1)
Benkendorff...			86.9	13.2			(53.1)
Baku (a v. analysis)...			86.0	13.0		1.0	(53.1)
Balachany- Ssabuntschi	0.882		87.4	12.5		0.1	(53.1)
Binagady.....	0.913		85.5	12.0	2.4	0.41	(53.1)

*Caucasian*.—Almost entirely naphthene hydrocarbons. Small amounts of phenols, naphthenic acids and other aromatics (143).

Caucasian....			86.9	13.3		0.064	(143)
Caucasian....	0.940	20	85.3	11.6		3.1	(169)
Caucasian....	0.887	0	84.2	12.4		3.4	(169)
Fergana- Tschimeon...	0.872		85.8	13.6		0.08	(53.1)
Grozni.....	0.850		86.0	13.0	0.07	0.74	(53.1)
Grozni.....	0.906		86.4	13.0	0.07	0.4	(53.1)
Transcaspian..			86.9	12.2	0.80	0.16	(53.1)
Transcaspian..	0.873		86.6	12.4	0.14	0.37	(53.1)
Tscheleken...	0.874		86.4	12.4		0.38	(53.1)
Uchta.....	0.928		85.5	12.2	0.20	1.03	(53.1)
Uchta.....	0.897		85.3	12.5	0.14	1.21	(53.1)

## Africa—EGYPT

	0.907	15.5	85.15	11.71	0.892	2.25	(82)
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Mixture of paraffin- and asphalt-base oils rich in sulfur.

## Asia—INDIA

Assam							
Digboi*.....	0.856	15.5	86.3	12.9	0.2	0.45	(216)
Badarpur†....			88.8	10.8	0.2	0.1	(216)
Burma‡.....	0.835		86.45	13.25	0.2	0.1	(216)
Rangoon§....	0.875	28.2	83.8	12.7	3.5		(169)

\* Mixed-base oil with small amount naphthenic acid. Low-boiling distillate contains aromatics.

† No solid paraffins and little asphalt. Empirical composition  $\text{C}_n\text{H}_{1.47}$ .

‡ Mixed-base petroleum containing solid paraffins and asphalt. Aromatics and small amounts of naphthenic acids in the lighter distillates.

§  $\text{C}_{20}\text{H}_{42}$ ,  $\text{C}_{22}\text{H}_{44}$ ,  $\text{C}_{24}\text{H}_{48}$ ,  $\text{C}_{26}\text{H}_{52}$ , xylene and isocumene isolated (205).

## JAPAN (138)

Chiefly the  $\text{C}_n\text{H}_{2n}$  series. Aromatics much smaller than in California.

Amaze.....	0.8240	20	84.66	13.22	0.35	1.32	0.22
Hirei.....	0.8622	20	83.28	13.19	0.74	1.83	0.41
Katsubo.....	0.8771	20	84.52	13.12	0.97	0.21	0.82
Kitatany.....	0.8952	20	83.05	13.05	0.75	0.24	0.61
Koguchi.....	0.9435	20	83.91	13.60	1.34	0.41	0.49
Kosudsu.....	0.9210	20	84.49	13.40	1.23	0.30	0.37
Miyagawa.....	0.8911	20	84.86	13.83	0.5	0.20	0.32

## PERSIA

Maidan-I-Naf- tun*.....	0.837		85.4	12.8	0.76	1.96	(47)
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\* Mixed-base oil. Gasolene fraction contains ca. 10 % aromatics.

## East Indies—BORNEO

Sarawak*.....	0.902	15	86.47	12.37	0.13	0.68	0.35	(104)
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\* Naphthene-base oil, with paraffin-base oils at the 1950-foot level. Small amounts aromatics.

## JAVA

Rembang.....	0.923	0	87.1	12.0	0.9		(169)
Cheribon.....	0.827	0	83.6	14.0	2.4		(169)
Surabaya.....	0.972	0	85.0	11.2	2.8		(169)

## PROXIMATE COMPOSITION

For comprehensive tables covering the chief producing fields of the world see (39, 53.1); for extensive tables of data on North and South American crudes, see (108).

Below are given the data for the oil fields of the United States as collected from the reports of the U. S. Bureau of Mines, Reports of Investigations, Nos. 2293, 2595, 2608, 2235, 2364, 2322, 2202, 2416.

The various fractions ("cuts") used in these tables are defined by their distilling ranges or by their Saybolt viscosities ( $\eta$ ) at 100°F as follows:

1. Gasolene and naphtha. Below 200°C at 1 atm.
2. Kerosene. Between 200° and 275°C at 1 atm.
3. Gas oil. All vacuum fractions ( $p = 40$  mm) with  $\eta < 50$  sec.
4. Light lubricating distillate. All vacuum fractions ( $p = 40$  mm) with  $\eta$  between 50 and 99 sec.
5. Medium lubricating distillate. All vacuum fractions ( $p = 40$  mm) with  $\eta$  between 100 and 199 sec.
6. Viscous lubricating distillate. All vacuum fractions ( $p = 40$  mm) with  $\eta > 199$  sec.

Specific gravities ( $d$ ) are at 60/60F = 15.5/15.5C. % S = % sulfur.



Field	County	Lubricating distillates													
		Crude		Gasolene and naphtha		Kerosene		Gas oil		Light		Medium		Heavy	
		% S	d <sup>15.5</sup> <sub>15.5</sub>	%	d <sup>15.5</sup> <sub>15.5</sub>	%	d <sup>15.5</sup> <sub>15.5</sub>	%	d <sup>15.5</sup> <sub>15.5</sub>	%	d <sup>15.5</sup> <sub>15.5</sub>	%	d <sup>15.5</sup> <sub>15.5</sub>	%	d <sup>15.5</sup> <sub>15.5</sub>
ARKANSAS															
El Dorado.....	Union	0.83	0.852	30.7	0.735	13.0	0.823	12.0	0.857	11.3	0.882	4.6	0.903		
El Dorado.....	Union	.79	.853	28.8	.736	12.8	0.824	12.5	.853	10.8	.880	5.6	.908		
CALIFORNIA															
Coalinga (Eastside).....	Fresno	.67	.880	19.8	.775			34.1	.863	9.4	0.877-0.904	6.2	0.904-0.913	1.7	0.913-0.915
Coalinga (Eastside).....	Fresno	.71	.919	9.2	.782			29.9	.866	7.9	.901- .925	6.5	.925- .938	9.0	.938- .953
Coalinga (Eastside).....	Fresno	.45	.910	14.7	.782			29.4	.870	10.2	.898- .918	5.8	.918- .928	7.7	.928- .940
Coalinga (Eastside).....	Fresno	.51	.930	6.8	.804			26.8	.871	11.4	.906- .930	7.3	.930- .940	7.9	.940- .953
Coalinga (Oil City).....	Fresno	.10	.839	53.0	.788			36.8	.886						
Coalinga (Westside).....	Fresno	.71	.963	2.2	.808			18.7	.873	12.0	.901- .926	7.7	.926- .943	8.3	.943- .961
Belridge.....	Kern	.86	.911	23.8	.776			21.0	.872	5.5	.909- .926	5.0	.926- .940	11.4	.940- .956
North Belridge.....	Kern	.79	.885	33.4	.781			22.0	.854	6.1	.891- .913	3.8	.913- .929	7.3	.929- .946
North Belridge.....	Kern	.69	.875	34.5	.785			24.7	.855	6.3	.887- .911	4.4	.911- .924	6.1	.924- .938
Buena Vista.....	Kern	.50	.869	36.0	.761			21.8	.862	5.7	.904- .921	3.7	.921- .932	6.9	.932- .948
Buena Vista.....	Kern	.59	.890	28.0	.778			23.4	.864	6.5	.901- .920	6.5	.920- .936	6.7	.936- .946
Buena Vista.....	Kern	.59	.894	26.9	.783			23.1	.860	6.6	.896- .916	5.1	.916- .932	8.0	.932- .946
East Elk Hills.....	Kern	.68	.915	12.3	.781			31.4	.860	7.6	.905- .923	7.1	.923- .935	6.7	.935- .948
East Elk Hills.....	Kern	.61	.895	24.0	.786			25.0	.872	7.1	.900- .918	5.7	.918- .933	6.9	.933- .947
East Elk Hills.....	Kern	1.04	.948					27.2	.870	7.8	.908- .929	5.9	.929- .937	12.5	.937- .955
West Elk Hills.....	Kern	0.17	.773	81.1	.754	5.1	.816								
West Elk Hills.....	Kern	1.06	.917	12.2	.783			29.7	.858	7.2	.891- .916	3.3	.916- .923	9.8	.923- .953
Kern River.....	Kern	1.14	.977					16.0	.874	9.9	.910- .935	4.1	.935- .945	13.9	.945- .968
Kern River.....	Kern	1.07	.972					14.0	.868	6.1	.907- .928	5.3	.928- .943	15.1	.943- .960
Kern River.....	Kern	0.94	.971					12.2	.873	6.5	.901- .921	5.0	.921- .934	15.8	.934- .966
Lost Hills.....	Kern	0.85	.956	5.1	.798			19.0	.868	8.8	.917- .940	5.5	.940- .953	12.4	.953- .967
Lost Hills.....	Kern	0.99	.944	7.6	.777			23.6	.871	7.0	.914- .937	4.6	.937- .948	11.5	.948- .962
Lost Hills.....	Kern	0.66	.879	31.5	.766			20.4	.852	7.5	.883- .902	4.6	.902- .917	6.1	.917- .927
Maricopa Flat.....	Kern	1.07	.941	13.3	.759			20.9	.871	5.9	.916- .933	3.9	.933- .944	13.6	.944- .970
Maricopa Flat.....	Kern	0.60	.892	27.2	.771			21.9	.867	7.0	.904- .922	4.0	.922- .937	9.9	.937- .958
Maricopa Flat.....	Kern	0.75	.925	18.4	.790			21.5	.873	6.8	.913- .931	4.5	.931- .941	12.6	.941- .965
Maricopa Flat.....	Kern	0.69	.893	23.9	.772			21.1	.860	7.0	.884- .904	5.4	.904- .916	6.7	.916- .928
Maricopa Flat.....	Kern	1.29	.983					16.6	.877	5.3	.919- .934	5.0	.934- .948	18.3	.948- .974
Maricopa Flat.....	Kern	0.68	.895	24.1	.774			21.5	.859	7.1	.886- .903	5.2	.903- .915	8.9	.915- .928
McKittrick.....	Kern	1.02	.965	2.1	.810			19.9	.873	6.9	.911- .932	6.6	.932- .950	17.2	.950- .988
McKittrick.....	Kern	0.91	.943	11.1	.796			22.3	.874	7.1	.913- .934	5.9	.934- .951	14.4	.951- .970
McKittrick (front).....	Kern	1.38	.982					14.5	.878	6.6	.910- .931	6.6	.931- .949	19.9	.949- .984
Midway.....	Kern	1.00	.967					15.4	.844	7.6	.916- .935	5.4	.935- .950	17.4	.950- .968
North Midway.....	Kern	0.96	.982					10.8	.880	9.8	.899- .931	5.5	.931- .948	16.6	.948- .978
North Midway.....	Kern	0.88	.936	7.1	.787			26.7	.870	8.3	.907- .932	4.1	.932- .936	11.9	.936- .963
North Midway.....	Kern	0.98	.962	3.3	.806			17.5	.879	7.3	.911- .930	5.1	.930- .943	16.7	.943- .966
North Midway.....	Kern	1.01	.978					15.4	.880	7.4	.909- .937	6.0	.937- .952	16.3	.952- .971
North Midway.....	Kern	1.63	.987					10.2	.887	7.7	.909- .935	5.4	.935- .949	19.9	.949- .971
North Midway.....	Kern	1.01	.971					18.2	.874	8.4	.910- .933	6.2	.933- .949	13.7	.949- .977
North Midway.....	Kern	0.92	.936	9.6	.778			23.7	.874	7.2	.909- .926	4.7	.926- .936	14.4	.936- .958
Sunset.....	Kern	1.16	.981					19.3	.877	5.2	.904- .928	5.5	.928- .943	20.9	.943- .969
Sunset.....	Kern	0.84	.956	2.9	.824			18.3	.872	8.2	.889- .912	5.7	.912- .936	10.2	.936- .957
Sunset.....	Kern	0.73	.878	17.0	.777			26.9	.865	7.5	.908- .923	6.3	.923- .935	8.5	.935- .952
Brea.....	Los Angeles	2.99	.984	6.6	.805			19.4	.875	6.5	.913- .943	3.0	.943- .950	16.4	.950- .975
Coyote Hills.....	Los Angeles	1.46	.899	20.5	.764	4.7	.819	17.9	.847	8.2	.873- .898	5.6	.898- .911	5.7	.911- .924
Long Beach.....	Los Angeles	1.25	.904	18.9	.763	5.7	.821	17.5	.857	7.0	.882- .903	4.7	.903- .917	5.6	.917- .931
Long Beach.....	Los Angeles	1.29	.897	19.8	.755	3.7	.823	17.3	.854	8.0	.879- .905	4.5	.905- .917	7.2	.917- .936
Long Beach.....	Los Angeles	0.80	.872	29.3	.757	4.4	.818	17.7	.848	8.8	.874- .901	5.0	.901- .914	4.2	.914- .926
Long Beach.....	Los Angeles	1.16	.892	24.1	.762	4.1	.818	17.5	.852	7.2	.879- .898	5.2	.898- .912	5.0	.912- .931
Long Beach.....	Los Angeles	1.59	.908	15.8	.768			19.4	.850	6.8	.884- .907	5.3	.907- .920	8.1	.920- .938
Long Beach.....	Los Angeles	1.34	.920	20.0	.763	4.5	.824	16.6	.856	6.5	.884- .905	5.7	.905- .921	7.2	.921- .934
Montebello.....	Los Angeles	0.96	.951					19.4	.876	10.2	.905- .925	7.3	.925- .936	9.2	.936- .947
Montebello.....	Los Angeles	2.19	.954	6.7	.785			25.9	.867	5.2	.905- .920	5.1	.920- .929	7.0	.929- .950
Montebello.....	Los Angeles	0.79	.916	11.1	.794			25.4	.864	10.2	.885- .905	6.5	.905- .916	8.7	.916- .928
Montebello.....	Los Angeles	0.75	.916	10.6	.800			28.1	.866	9.8	.890- .907	9.3	.907- .920	6.9	.920- .929
Salt Lake.....	Los Angeles	2.73	.967	8.3	.793			12.8	.868	6.0	.897- .918	7.1	.918- .942	13.5	.942- .964
Santa Fe Springs.....	Los Angeles	0.54	.867	27.9	.769			31.3	.852	9.2	.873- .894	3.2	.894- .901		
Santa Fe Springs.....	Los Angeles	0.56	.878	24.6	.778			27.7	.850	10.8	.870- .894	5.4	.894- .907	2.1	.907- .915
Santa Fe Springs.....	Los Angeles	0.45	.851	36.7	.760	5.3	.819	20.3	.848	8.9	.870- .898	2.9	.898- .907	4.4	.907- .919
Santa Fe Springs.....	Los Angeles	0.54	.888	18.8	.788			30.8	.850	10.2	.875- .897	4.8	.897- .908	5.8	.908- .921
Santa Fe Springs.....	Los Angeles	0.45	.853	35.5	.758	5.3	.821	20.3	.850	8.0	.871- .894	4.6	.894- .906	3.1	.906- .912
Santa Fe Springs.....	Los Angeles	0.45	.854	35.4	.763	5.1	.823	19.0	.847	9.9	.868- .898	3.6	.898- .905	4.0	.905- .913
Santa Fe Springs.....	Los Angeles	0.40	.855	34.3	.763	5.5	.822	20.8	.851	8.6	.875- .899	6.7	.899- .912	1.2	.912- .914
Santa Fe Springs.....	Los Angeles	0.44	.859	33.3	.763	6.3	.823	20.1	.850	9.5	.873- .901	4.9	.901- .909	3.0	.909- .914
Torrence.....	Los Angeles	1.62	.917	14.6	.774			21.5	.853	10.0	.884- .911	5.1	.911- .921	4.3	.921- .930
Whittier.....	Los Angeles	0.56	.916	18.8	.795			26.4	.869	6.5	.905- .922	4.7	.922- .936	10.3	.936- .951
Whittier.....	Los Angeles	0.77	.942	8.2	.804			22.4	.872	9.4	.901- .924	4.1	.924- .935	6.3	.935- .949
Fullerton.....	Los Angeles	1.43	.920	18.1	.771			21.3	.858	7.6	.887- .909	6.7	.909- .923	5.3	.923- .933
Huntington Beach.....	Orange	1.42	.905	18.4	.750	3.7	.817	15.6	.846	9.2	.869- .896	5.2	.896- .911	5.0	.911- .923
Huntington Beach.....	Orange	1.29	.897	22.3	.763	4.1	.821	17.2	.853	7.9	.879- .903	5.2	.903- .		



Field	County	Crude		Gasolene and naphtha		Kerosene		Gas oil		Lubricating distillates							
										Light		Medium		Heavy			
		% S	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$		
CALIFORNIA—(Continued)																	
Huntington Beach.....	Orange	2.00	0.938	12.0	0.790			19.8	0.858	7.1	0.889-0.910	5.0	0.910-0.923	7.2	0.923-0.940		
Huntington Beach.....	Orange	1.31	.892	25.0	.764	3.5	0.825	16.2	.853	7.0	.878- .900	5.4	.900- .915	5.9	.915- .925		
Huntington Beach.....	Orange	2.07	.922	16.7	.769	3.3	.825	17.1	.854	7.7	.883- .911	4.4	.911- .922	6.5	.922- .934		
Rich.....	Orange	1.09	.920	14.7	.785			21.0	.859	7.9	.884- .906	6.4	.906- .919	5.0	.919- .929		
Richfield.....	Orange	1.60	.899	25.2	.752	3.8	.821	16.8	.854	7.7	.876- .903	5.9	.903- .919	6.9	.919- .933		
Casmalia.....	Santa Barbara	2.84	1.023					26.8	.842	2.0	.897- .917	12.7	.917- .966	7.6	.966- .982		
Cat Canyon.....	Santa Barbara	4.13	.960	9.8	.781			25.5	.854	5.6	.906- .923	5.6	.923- .936	7.8	.936- .949		
Santa Maria.....	Santa Barbara	2.63	.916	21.8	.768			21.2	.856	6.6	.893- .916	4.5	.916- .929	5.7	.929- .943		
Summerland.....	Santa Barbara	0.54	.975					14.8	.873	6.6	.913- .939	5.5	.939- .956	13.1	.956- .978		
Sargent.....	Santa Clara	0.86	.952	8.3	.776			23.3	.878	7.7	.920- .944	4.1	.944- .953	11.7	.953- .972		
Arroyo Grande.....	San Luis Obispo	1.30	.967	5.3	.805			17.3	.872	6.2	.904- .926	4.2	.926- .939	11.9	.939- .963		
Bardsdale.....	Ventura	0.83	.873	26.8	.762	5.1	.817	20.0	.844	9.3	.873- .902	7.3	.902- .918	2.3	.918- .923		
Conejo.....	Ventura	0.52	.970					11.0	.885	8.4	.902- .920	7.6	.920- .935	20.7	.935- .959		
Ojai.....	Ventura	1.63	.952	13.0	.780			18.6	.869	6.5	.907- .932	4.6	.932- .947	10.9	.947- .963		
Santa Paula.....	Ventura	0.55	.918	13.1	.789			29.5	.860	7.4	.899- .923	3.6	.923- .936	12.4	.936- .945		
Simi.....	Ventura	0.68	.864	32.9	.759	5.2	.820	18.9	.853	7.4	.876- .900	4.6	.900- .915	5.4	.915- .929		
South Mountain.....	Ventura	1.73	.886	25.5	.753	4.5	.817	16.9	.848	8.7	.871- .899	7.0	.899- .915	2.1	.915- .922		
Ventura.....	Ventura	1.15	.875	28.6	.749	4.4	.820	17.2	.847	8.5	.873- .898	4.9	.898- .911	4.5	.911- .923		
Ventura.....	Ventura	0.47	.794	64.4	.757	15.9	.812	8.1	.843								
Ventura.....	Ventura	0.90	.880	22.4	.756	11.0	.816	15.2	.847	14.1	.865- .902	7.5	.902- .917	1.2	.917- .920		
Composite sample.....	Ventura	1.79	.907	23.7	.757	4.5	.825	17.1	.858	8.3	.882- .912	4.6	.912- .923	5.6	.923- .936		
COLORADO																	
Florence.....	Fremont and Pueblo	0.17	.880	8.9	.758	14.5	.808	16.2	.842	13.3	0.871	8.3	0.892				
Rangely.....	Rio Blanca	.06	.819	34.6	.748	19.3	.810	12.3	.844	11.7	.860	5.6	.880				
ILLINOIS																	
INDIANA																	
Lima.....	†	.48	.846	26.0	.753	19.2	.817	10.2	.843	10.9	.869	6.8	.885				
KANSAS																	
Iola.....	Allen	.66	.937	.8	.800	8.4	.842	4.7	.876	14.0	.891	8.2	.907	6.9	0.923		
Moran and Elsmore.....	Allen	.32	.875	20.2	.758	15.3	.826	6.9	.856	12.6	.875	10.8	.898				
Augusta.....	Butler	.41	.865	24.2	.761	20.5	.830	11.1	.863	11.4	.890	5.5	.904				
Cattlemen.....	Butler	.30	.838	32.8	.736	15.3	.819	9.8	.859	10.0	.879	5.1	.895				
Elbing.....	Butler	.29	.856	29.8	.751	20.7	.826	13.3	.864	10.8	.888	5.0	.908				
Eldorado.....	Butler	.29	.853	27.3	.754	20.5	.822	12.1	.861	11.1	.885	5.7	.902				
Potwin.....	Butler	.14	.807	45.0	.730	17.1	.813	9.9	.850	8.2	.872	3.9	.890				
Peru Sedan.....	Chautauqua	.25	.875	19.0	.760	16.3	.824	10.7	.863	6.4	.876	11.0	.895				
Peru Sedan.....	Chautauqua	.24	.882	12.6	.791	18.4	.839	5.3	.863	14.9	.878	14.0	.895				
Peru Sedan.....	Chautauqua	.12	.858	20.6	.755	17.1	.817	11.3	.856	11.9	.875	7.3	.891				
Peacock.....	Cowley	.23	.853	25.9	.763	20.2	.821	11.2	.860	11.7	.878	6.3	.896				
Elrod.....	Cowley	.20	.853	25.9	.753	18.6	.820	11.2	.858	10.9	.878	6.7	.897				
New Albany.....	Elk	.27	.866	24.7	.748	13.9	.822	10.7	.857	9.9	.878	5.5	.896				
Rantoul.....	Franklin	.51	.880	22.4	.740	14.0	.824	9.2	.864	5.8	.878	6.7	.898				
Sallyyard.....	Greenwood and But- ler	.24	.839	33.2	.737	16.6	.821	9.8	.857	9.7	.877	5.0	.893				
Tester.....	Greenwood	.19	.841	30.1	.752	18.5	.819	11.3	.857	10.9	.875	5.3	.895				
Florence and Peabody.....	Marion	.23	.861	25.1	.761	18.2	.829	13.3	.859	12.1	.884	6.4	.901				
Osawatomie.....	Miami	.57	.892	17.1	.753	16.3	.820	9.8	.862	5.5	.880	11.8	.901				
Independence.....	Montgomery	.24	.855	25.3	.767	17.0	.821	13.4	.857	5.5	.878	10.8	.894				
Tyro.....	Montgomery	.34	.879	14.2	.771	15.4	.828	11.5	.859	6.2	.875	12.7	.894				
Wayside.....	Montgomery	.37	.885	17.3	.754	14.6	.821	11.1	.862	5.3	.877	9.8	.891				
Chanute.....	Neosho	.31	.878	15.9	.768	17.6	.828	11.5	.864	12.9	.884	7.8	.900				
Erie.....	Neosho	.30	.870	21.2	.745	16.2	.823	11.9	.864	6.6	.880	5.7	.894	6.1	.904		
Urbana.....	Neosho	.32	.876	18.8	.759	16.3	.828	4.7	.861	19.1	.877	6.0	.900				
Altoona.....	Wilson	.25	.865	16.2	.761	17.0	.812	11.4	.853	12.5	.872	6.7	.893				
Neodesha.....	Wilson	.23	.846	29.9	.741	15.0	.818	10.5	.855	11.1	.875	4.4	.894				
Yates Center.....	Woodson	.46	.889	7.8	.808	18.9	.838	14.6	.859	15.2	.879	6.7	.896				
KENTUCKY																	
Olympia.....	Bath	.23	.853	11.2	.757	24.5	.804	11.5	.841	12.8	.860	6.5	.872				
Ragland.....	Bath	.31	.902	12.6	.767	16.0	.826	8.7	.856	11.6	.878	5.4	.898				
	Lawrence	.21	.835	33.1	.744	18.4	.818	7.7	.846	10.1	.873	6.0	.896				
Big Sinking.....	Lee and Estell	.14	.844	31.2	.751	17.3	.819	10.6	.849	10.8	.876	5.9	.891				
Composite from several counties..		.23	.835	35.4	.735	16.2	.824	9.3	.851	9.5	.874	4.6	.894				
	Wayne	.49	.869	35.9	.751	17.3	.839	11.0	.862	10.5	.887	5.0	.898				
Cow Creek.....	Wolf and Estell	.13	.866	19.7	.771	16.7	.828	10.4	.855	12.6	.871	7.1	.883				
Ross Creek.....	Wolf, Lee and Jack- son	.12	.838	35.9	.744	14.6	.826	9.7	.848	10.3	.874	5.9	.894				
Compton.....	Wolf	.23	.842	30.8	.747	16.7	.821	10.3	.850	10.4	.870	6.0	.882				
LOUISIANA (North)																	
Elmgrove.....	Bossier	.27	.879	13.5	.793	18.5	.841	16.7	.858	15.8	.878	7.2	.904				
Caddo.....	Caddo	.25	.850	25.7	.751	18.9	.806	12.5	.841	11.7	.864	5.9	.879				

\* Lawrence, Crawford, Jasper and Cumberland.

† Composite from Allen and other counties.

Field	County	Crude		Gasolene and naphtha		Kerosene		Gas oil		Lubricating distillates					
										Light		Medium		Heavy	
		% S	d <sup>15.6</sup> <sub>15.6</sub>	%	d <sup>15.6</sup> <sub>15.6</sub>	%	d <sup>15.6</sup> <sub>15.6</sub>	%	d <sup>15.6</sup> <sub>15.6</sub>	%	d <sup>15.6</sup> <sub>1.66</sub>	%	d <sup>15.6</sup> <sub>15.6</sub>	%	d <sup>15.6</sup> <sub>15.6</sub>
LOUISIANA (North) (Continued)															
Caddo.....	Caddo	0.21	0.820	35.2	0.748	22.4	0.795	11.1	0.842	9.9	0.864	5.2	0.884		
Pine Island.....	Caddo	.42	.901	3.0	.828	18.3	.868	7.5	.892	17.1	.899	15.6	.907		
Homer.....	Claiborne	.63	.844	30.2	.736	15.5	.812	10.5	.854	11.0	.875	5.9	.892		
DeSoto, Red River and Bull Bayou.	DeSoto and Red River	.21	.822	27.6	.764	36.1	.805	11.8	.845	8.4	.868	3.7	.895		
LOUISIANA (South)															
Jennings.....	Acadia	.37	.911					40.5	.880	12.4	0.909-0.922	7.5	0.922-0.929	13.6	0.929-0.944
Jennings.....	Acadia	.36	.908					45.6	.873	14.7	.902-.921	8.1	.921-.930	8.7	.930-.944
Edgerly.....	Calcasieu	.68	.925					25.9	.879	15.0	.896-.914	8.0	.914-.935	14.2	.935-.972
Vinton.....	Calcasieu	.33	.936					22.9	.884	13.8	.913-.935	8.2	.935-.945	16.8	.945-.962
Anse La Butte.....	St. Martin's	.22	.919					34.8	.881	14.6	.909-.920	8.0	.920-.928	16.1	.928-.944
Anse La Butte.....	St. Martin's	.30	.903					34.1	.867	16.1	.896-.912	9.5	.912-.920	8.2	.920-.936
MONTANA															
Winnett.....	Musselshell	.36	.781	63.2	.747	25.5	.814								
NEW YORK															
	Alleghany	.10	.828	30.0	.748	17.5	.802	10.3	.838	11.3	0.854	6.3	0.873		
OHIO															
North Lima.....	Allen	.55	.835	31.0	.749	19.2	.815	9.9	.843	10.7	.870	5.5	.890		
South Lima.....	Allen, Auglaize and Mercer	.55	.842	27.0	.758	20.0	.818	10.8	.841	11.5	.869	4.9	.889		
Lima.....	Composite from Allen and others	.48	.846	26.0	.753	19.2	.817	10.2	.843	10.9	.869	6.8	.885		
Corning.....	Washington	.10	.838	27.8	.740	17.0	.805	9.7	.835	10.5	.854	6.3	.871		
Penn Grade.....	Washington	.05	.805	33.5	.739	20.2	.798	11.3	.834	11.2	.855	5.5	.868		
OKLAHOMA															
Cement.....	Caddo	.19	.852	20.2	.766	20.7	.809	14.0	.846	6.7	.864	13.3	.880		
Heraldton.....	Carter	.72	.870	22.3	.753	15.8	.825	10.5	.862	6.5	.880	12.1	.897		
Hewitt.....	Carter	.72	.858	26.6	.737	14.3	.817	9.5	.860	4.8	.877	12.4	.899		
Walters.....	Cotton	.42	.859	27.7	.747	17.7	.813	10.9	.860	5.2	.877	9.3	.899		
North Bristow.....	Creek	.25	.824	38.8	.743	18.1	.820	10.7	.858	9.2	.880	4.6	.899		
Cushing.....	Creek	.28	.828	37.5	.743	18.0	.818	11.5	.855	9.6	.876	4.7	.896		
Glen.....	Creek and Tulsa	.30	.862	24.8	.762	17.4	.827	12.5	.860	5.2	.878	11.5	.898		
Kellyville.....	Creek	.28	.883	14.6	.771	15.9	.830	5.9	.861	12.1	.891	6.3	.892	5.8	0.903
Mounds.....	Creek	.26	.853	28.2	.750	15.8	.829	9.5	.861	11.2	.883	6.0	.899		
Slick.....	Creek	.44	.875	22.9	.746	13.0	.832	5.9	.856	11.4	.884	4.5	.902		
Garber.....	Garfield	.14	.799	52.4	.737	15.7	.816	3.9	.844	11.9	.870	2.7	.891		
Blackwell or Dilsworth.....	Kay	.24	.830	36.3	.748	18.0	.817	10.7	.856	9.3	.877	4.8	.898		
Newkirk or Mervine.....	Kay	.15	.823	35.9	.743	18.9	.815	11.2	.850	11.1	.868	4.1	.884		
Arbuckle.....	Marshall	.06	.794	46.2	.726	17.8	.804	9.4	.839	8.2	.858	3.4	.874		
Madill.....	Marshall	.06	.769	85.5	.748	10.5	.806								
Boynton.....	Muskogee	.15	.841	24.1	.762	19.6	.816	13.0	.850	12.4	.870	5.9	.879		
Muskogee.....	Muskogee	.23	.852	19.5	.762	17.8	.820	13.9	.850	12.2	.868	7.3	.883		
Billing.....	Noble	.16	.823	40.4	.739	17.6	.819	10.7	.858	9.6	.875	4.8	.890		
Bluff and Alluwe.....	Nowata	.19	.865	22.1	.763	19.5	.829	10.7	.863	13.8	.886	5.1	.906		
Delaware Extension.....	Nowata	.23	.859	25.3	.757	17.6	.827	13.2	.862	12.4	.886	6.1	.902		
Delaware and Lenapak.....	Nowata	.19	.869	19.9	.765	19.1	.826	11.4	.865	6.0	.880	11.5	.901		
Deaner.....	Okfuskee	.13	.826	32.1	.740	16.4	.817	11.3	.853	10.6	.876	5.9	.893		
Lyons.....	Okfuskee	.14	.836	28.3	.752	17.4	.816	11.5	.853	11.1	.869	6.1	.888		
Bald Hill.....	Okmulgee	.15	.816	37.6	.737	16.4	.817	10.5	.854	10.4	.874	4.8	.890		
Beggs.....	Okmulgee	.15	.830	29.9	.749	14.9	.823	6.4	.853	14.1	.876	5.5	.894		
Henryetta.....	Okmulgee	.13	.842	25.3	.754	18.3	.819	12.1	.854	11.1	.873	5.9	.885		
Okmulgee.....	Okmulgee	.13	.854	17.3	.759	17.3	.815	14.7	.849	12.8	.867	7.5	.878		
Philipsville.....	Okmulgee	.17	.809	39.6	.728	15.4	.817	9.0	.850	10.0	.870	4.1	.886		
Youngstown.....	Okmulgee	.32	.870	22.2	.760	16.0	.828	13.0	.862	4.7	.879	5.4	.890	6.8	.901
Bigheart.....	Osage	.19	.846	28.1	.754	19.1	.827	11.4	.862	6.6	.879	10.9	.892		
Burbank.....	Osage	.32	.837	29.7	.746	16.9	.822	4.7	.846	12.7	.868	10.6	.894		
Hominy.....	Osage	.13	.840	30.9	.745	19.1	.827	11.6	.862	6.9	.883	9.7	.893		
Osage.....	Osage	.23	.846	28.9	.751	18.0	.824	5.2	.858	13.1	.870	10.8	.889		
Pershing.....	Osage	.17	.846	26.4	.751	19.9	.825	6.4	.860	12.2	.874	5.5	.895	6.2	.903
Cleveland.....	Pawnee	.26	.841	30.6	.753	19.8	.821	8.3	.858	5.5	.875	10.1	.897		
Jennings.....	Pawnee	.33	.840	32.9	.750	18.6	.820	11.7	.855	10.2	.876	5.4	.894		
Yale or Quay.....	Payne	.33	.858	24.8	.756	17.8	.818	9.7	.862	10.6	.879	4.9	.897		
Allen.....	Pontotoc	.62	.878	22.7	.751	16.5	.826	9.7	.867	5.6	.888	14.9	.901		
Claremore.....	Rogers	.14	.855	23.8	.761	19.2	.822	12.0	.855	11.6	.878	6.5	.895		
Comanche.....	Stephens	.41	.857	26.3	.755	17.1	.820	11.0	.864	5.2	.878	10.5	.895		
Duncan.....	Stephens	.40	.848	31.4	.746	18.0	.815	10.4	.857	6.0	.875	11.6	.897		
Owasso.....	Tulsa and Rogers	.27	.851	26.9	.761	18.8	.826	12.6	.858	5.9	.875	11.1	.888		
Skiatook, Sperry and Turley.....	Tulsa	.23	.868	20.3	.773	18.5	.833	6.4	.864	12.8	.875	13.6	.901		
Broken Arrow.....	Wagoner and Tulsa	.19	.853	26.2	.764	17.8	.825	10.9	.858	11.5	.881	5.2	.896		
Wagoner.....	Wagoner	.15	.864	16.9	.765	17.5	.820	11.1	.852	12.4	.872	7.2	.897		
Bartlesville.....	Washington	.25	.871	19.0	.779	18.5	.837	7.3	.867	13.6	.881	13.2	.899		
Canary.....	Washington	.32	.867	20.4	.771	19.2	.830	13.5	.864	6.1	.882	12.9	.894		
Ochelata Hogshooter.....	Washington	.27	.864	22.0	.767	17.7	.826	6.5	.859	13.1	.875	5.1	.891	8.4	.910



Field	County	Crude		Gasolene and naphtha		Kerosene		Gas oil		Lubricating distillates							
		% S	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	Light		Medium		Heavy			
										%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$		
PENNSYLVANIA																	
	Allegheny and Wash.	0.08	0.800	37.8	0.733	20.2	0.792	9.6	0.831	9.3	0.848	5.7	0.859				
	Green	.08	.815	29.0	.745	18.7	.803	10.2	.834	11.9	.850	6.1	.865				
Special Franklin Crude.....	McKean	.10	.823	32.5	.739	17.8	.802	9.4	.839	10.6	.853	5.7	.867				
	Mercer	.09	.863	9.0	.824	15.1	.842	13.7	.850	13.5	.866	8.4	.876				
Composite.....		.08	.811	33.9	.734	19.9	.802	9.7	.835	11.1	.852	6.3	.865				
	Venango	.10	.819	29.6	.746	17.3	.806	10.9	.826	12.2	.850	5.2	.870				
	Venango	.08	.832	24.4	.761	16.4	.811	12.5	.827	12.2	.850	7.1	.870				
TEXAS (North)																	
Holiday.....	Archer	.41	.839	38.2	.734	16.3	.819	11.0	.858	9.1	.885	4.9	.908				
Brownwood.....	Brownwood	.17	.850	24.5	.747	16.5	.821	12.5	.862	13.7	.891	5.8	.905				
Petrolia.....	Clay	.38	.841	34.0	.752	18.7	.818	10.9	.856	5.1	.877	5.2	.890	5.7	0.907		
Santa Anna.....	Coleman	.16	.828	15.3	.782	18.6	.828	16.3	.852	14.6	.870	4.7	.885				
Desdemona.....	Comanche and East-land	.14	.839	29.4	.761	19.4	.817	14.0	.855	5.5	.873	11.0	.893				
Ranger.....	Eastland	.17	.840	30.2	.759	19.7	.821	12.1	.858	12.6	.867	9.9	.895				
Mexia.....	Limestone	.19	.847	17.3	.768	28.4	.807	17.3	.845	12.3	.869	4.9	.894				
Corsicana.....	Navarro	.24	.855	19.7	.765	23.8	.811	14.7	.859	6.7	.877	11.5	.896				
Strawn.....	Palo Pinto	.13	.847	24.4	.763	20.2	.819	11.7	.857	12.5	.876	6.7	.890				
Moran.....	Shackelford	.16	.830	34.4	.743	17.2	.816	11.6	.854	10.0	.877	4.7	.897				
Breckenridge.....	Stepheno	.28	.844	30.0	.757	18.8	.822	11.4	.860	10.9	.880	5.0	.900				
Caddo.....	Stepheno	.20	.839	30.5	.756	19.1	.820	11.8	.844	11.7	.864	4.3	.885				
Burkburnett.....	Wichita	.38	.838	36.3	.749	17.7	.822	10.8	.862	10.4	.885	5.1	.906				
Burkburnett.....	Wichita	.39	.841	36.7	.742	17.0	.820	10.8	.857	5.1	.880	9.4	.899				
Electra.....	Wichita	.25	.824	40.8	.734	16.1	.822	8.9	.860	6.0	.876	9.0	.896				
K. M. A.....	Wichita	.33	.836	35.1	.746	18.1	.821	10.4	.860	5.6	.878	6.2	.895	5.4	.915		
K. M. A.....	Wichita	.72	.854	31.2	.746	16.1	.819	9.4	.858	6.3	.880	9.6	.899				
Texhoma.....	Wichita	.33	.866	38.0	.739	17.2	.818	10.2	.858	5.0	.877	10.1	.897				
Thrall.....	Williamson	.15	.837	26.4	.763	20.8	.809	12.2	.847	11.7	.866	5.7	.880				
Young.....	Young	.26	.833	34.6	.750	18.7	.823	10.3	.859	5.5	.875	10.8	.892				
TEXAS (South)																	
Somerset.....	Atascosa	.42	.823	38.8	.735	18.3	.812	8.4	.851	10.8	0.858-0.889	5.2	0.889-0.904				
Somerset.....	Atascosa	1.40	.855	31.0	.746	10.7	.818	14.6	.854	8.4	.874- .898	7.4	.898- .916				
Yturri.....	Bexar	0.45	.863	24.6	.752	10.8	.813	14.3	.840	11.0	.858- .883	6.6	.883- .901	2.7	0.901-0.909		
Damon Mound.....	Brazoria	.28	.923					36.9	.886	14.9	.915- .933	8.4	.933- .939	14.1	.939- .948		
Damon Mound.....	Brazoria	.36	.921	5.8	.818			36.5	.874	16.4	.913- .933	6.0	.933- .940	17.5	.940- .965		
West Columbia.....	Brazoria	.29	.934					27.0	.851	13.8	.917- .933	8.2	.933- .943	20.7	.943- .958		
West Columbia.....	Brazoria	.21	.906					48.8	.878	10.4	.911- .916	13.2	.916- .923	8.0	.923- .927		
West Columbia.....	Brazoria	.45	.940					28.6	.886	12.0	.918- .934	7.5	.934- .945	15.9	.945- .957		
Barbers Hill.....	Chambers	.67	.858	31.0	.757	5.5	.825	18.6	.854	8.0	.885- .906	4.7	.906- .912	5.9	.912- .918		
Pierdes-Pintos.....	Duvall	.55	.927					33.9	.870	10.8	.894- .919	9.4	.919- .948	21.9	.948- .960		
Blue Ridge.....	Fort Bend	.45	.944					21.8	.883	11.4	.922- .937	7.6	.937- .947	18.1	.947- .968		
Blue Ridge.....	Fort Bend	.39	.894	16.2	.784			23.7	.867	12.7	.896- .909	5.9	.909- .927	11.2	.927- .960		
Batson.....	Hardin	.61	.903	8.2	.789			34.9	.876	11.4	.908- .920	8.2	.920- .928	8.1	.928- .939		
Saratoga.....	Hardin	.57	.977					16.8	.883	9.0	.919- .934	8.6	.934- .950	15.3	.950- .977		
Sour Lake.....	Hardin	.43	.884	16.7	.765			30.6	.874	10.6	.907- .927	6.0	.927- .932	9.4	.932- .939		
Goose Creek.....	Harris	.22	.926					28.5	.887	14.2	.911- .926	8.3	.926- .935	15.3	.935- .952		
Goose Creek.....	Harris	.20	.917					36.0	.882	14.2	.914- .924	7.4	.924- .930	14.7	.930- .943		
Goose Creek.....	Harris	.21	.910					39.2	.876	13.7	.909- .919	7.5	.919- .928	11.2	.928- .961		
Goose Creek.....	Harris	.55	.897					51.7	.872	13.2	.900- .915	7.4	.915- .927	7.1	.927- .943		
Goose Creek.....	Harris	.49	.931					31.0	.886	9.3	.915- .926	7.3	.926- .935	18.2	.935- .956		
Humble.....	Harris	.43	.938					24.8	.885	3.2	.912- .918	20.0	.918- .947	17.1	.947- .961		
Humble.....	Harris	2.40	.948	3.7	.823			24.9	.882	14.4	.913- .931	7.7	.931- .942	10.6	.942- .962		
Pierce Junction.....	Harris	0.29	.921					36.2	.880	16.4	.922- .940	5.8	.940- .946	13.8	.946- .963		
Spindle Top.....	Jefferson	2.31	.936					28.5	.880	13.8	.910- .925	8.6	.925- .937	17.8	.937- .955		
Hull.....	Liberty	0.35	.863	26.6	.762			27.3	.858	10.4	.886- .905	7.0	.905- .918	7.7	.918- .932		
Hull.....	Liberty	.44	.926	3.8	.800			22.0	.871	11.1	.901- .916	6.6	.916- .924	15.6	.924- .945		
North Dayton.....	Liberty	.50	.899	9.8	.796			45.5	.884	11.8	.924- .937	7.2	.937- .939	8.6	.939- .942		
Markham.....	Matagorda	.18	.831	50.2	.782	9.3	.809	26.5	.850								
Nacogdoches.....	Nacogdoches	.39	.923					19.5	.877	14.9	.891- .905	12.6	.905- .915	8.8	.915- .921		
Orange.....	Orange	.45	.912					31.9	.869	13.6	.896- .911	9.7	.911- .926	8.0	.926- .930		
Terry.....	Orange	.34	.881					27.0	.880	13.6	.901- .920	7.2	.920- .928	16.0	.928- .939		
Mirando.....	Zapata	.25	.923					49.8	.893	14.0	.915- .931	4.5	.931- .941	14.8	.941- .969		
WEST VIRGINIA																	
Maryland Grade.....	Hancock	.084	.783	45.9	.718	16.5	.794	8.4	.839	8.3	0.848	4.3	0.858				
Maryland Grade.....	Harrison and Dodd-ridge	.20	.808	29.5	.741	18.9	.795	9.0	.823	11.5	.840	7.2	.859				
Maryland Grade.....	Harrison and others	.27	.800	34.4	.735	20.4	.795	9.8	.823	12.1	.843	4.0	.864				
Blue Creek.....	Kanawha	.11	.810	49.2	.727	18.0	.797	9.2	.829	9.1	.849	4.6	.862				
Cabin Creek.....	Kanawha	.19	.797	40.5	.730	21.0	.797	8.0	.827	8.9	.844	4.2	.856				
Kelly Creek.....	Kanawha	.11	.799	39.6	.731	18.4	.798	9.9	.829	9.8	.847	4.5	.859				
Eureka Grade.....	*	.10	.805	34.3	.739	18.5	.799	12.1	.825	11.0	.844	5.6	.856				
Eureka Grade.....	*	.24	.806	37.7	.734	17.7	.801	9.2	.829	9.6	.845	6.0	.848				

\* Ritchie, Wood, Wirt, Calhoun, Roan and Kanawha.

Field	County	Lubricating distillates													
		Crude		Gasolene and naphtha		Kerosene		Gas oil		Light		Medium		Heavy	
		% S	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$
WEST VIRGINIA (Continued)															
Maryland Grade.....	*	0.28	0.805	38.3		18.0	0.804	9.3	0.825	9.3	0.852	5.2	0.872		
Maryland Grade.....	Tyler	.095	.804	35.8	0.744	20.8	.795	10.6	.824	11.2	.844	4.8	.862		
Eureka Grade.....	Tyler, Doddridge, and Wetzel	.098	.808	34.0	.748	19.4	.810	9.9	.828	10.3	.844	5.3	.857		
Maryland Grade.....	Tyler, Doddridge, and Wetzel	.094	.803	37.1	.737	18.7	.798	10.1	.827	9.8	.839	4.8	.852		
Maryland Grade.....	Wetzel and Marshall	.11	.804	34.6	.732	19.1	.798	10.7	.827	10.0	.846	5.1	.862		
WYOMING															
Greybull.....	Bighorn	.08	.803	38.6	.738	17.8	.806	11.0	.830	10.9	.844	4.7	.858		
Ferris.....	Carbon	.19	.842	31.1	.747	13.4	.823	10.8	.847	11.7	.864	6.0	.881		
Lost Soldier.....	Carbon	.11	.875	16.7	.804	18.5	.854	18.6	.864	15.7	.875	6.7	.898		
Rock Creek.....	Carbon	.27	.843	31.4	.744	14.2	.826	10.0	.854	10.3	.876	5.4	.890		
Big Muddy.....	Converse	.17	.863	22.2	.762	15.7	.832	9.0	.860	11.1	.877	5.9	.890		
Dallas.....	Fremont	2.42	.914	12.8	.772	14.5	.827	10.8	.873	7.5	.897	7.0	.916	7.2	0.935
Lander.....	Fremont	2.62	.913	11.0	.755	16.0	.825	11.1	.869	15.1	.899	6.1	.921		
Maverick.....	Fremont	2.46	.922	8.6	.765	14.7	.824	10.9	.869	13.7	.901	8.0	.924		
Pilot Butte.....	Fremont	0.22	.848	24.0	.765	19.7	.815	13.2	.846	12.8	.864	5.9	.884		
Plunkett.....	Fremont	.55	.846	21.0	.779	22.6	.827	16.3	.852	14.0	.868	6.5	.883		
Grass Creek.....	Hot Springs	.14	.809	42.6	.741	20.0	.820	9.9	.850	9.3	.865	4.5	.881		
Hamilton Dome.....	Hot Springs	2.09	.903	17.6	.746	15.8	.826	8.7	.876	5.7	.893	12.4	.917		
Pine Mountain.....	Natrona	0.51	.953			Decomposed when heated at atmospheric pressure									
Salt Creek.....	Natrona	.18	.841	29.3	.750	15.7	.824	10.8	.847	11.1	.865	5.8	.880		
Shannon.....	Natrona	.20	.909	3.1	.838	11.1	.867	4.9	.884	19.1	.892	8.0	.905	8.4	.909
Lance Creek.....	Niobrara	.18	.823	33.5	.754	16.2	.812	11.3	.849	10.7	.859	6.0	.876		
Mule Creek.....	Niobrara	.14	.867	11.7	.768	17.4	.821	13.1	.850	14.6	.869	7.4	.882		
Elk Basin.....	Park	.14	.827	40.5	.748	17.4	.829	10.6	.862	9.8	.875	4.8	.890		
New Castle.....	Weston	.15	.840	31.6	.754	17.4	.826	10.3	.856	11.0	.871	5.6	.887		
Osage Range.....	Weston	.29	.837	34.8	.746	15.8	.825	9.8	.857	10.5	.873	5.1	.893		

\* Ritchie, Wood, Wirt, Calhoun, Roan, Kanawha and Gilmer.

### SPECIFIC GRAVITY AND THERMAL EXPANSION

In this section,  $S$  will be used to represent  $d_{15.56}^{15.56} \text{C} = d_{60}^{60} \text{F}$ .

#### CONVERSION FORMULAE

All weights in vacuo

$$^{\circ}\text{API} = \frac{141.5}{S} - 131.5. \quad ^{\circ}\text{Bé (American)} = \frac{140}{S} - 130$$

$$\text{Lb. per gal. (U. S.)} = 8.328 \times S$$

$$\text{Lb. per gal. (Brit.)} = 10.00 \times S$$

$$\text{Gal. (U. S.) per lb.} = 0.1201 \times S$$

$$\text{Gal. (Brit.) per lb.} = 0.1000 \times S$$

For other conversion factors, *v. vol. I*, p. 23. For elaborate computed conversion tables convenient for interpolation, *v. (10)*.

#### Crude Petroleums

The specific gravity of crudes varies with locality between the extreme limits 0.65 to 1.07. Below are given only those crudes for which values above 0.95 or below 0.75 have been recorded. The recorded data for all other crudes lie between the above values. For these *v. (26, 39, 53.1, 87, 120, 169)*.

#### SPECIFIC GRAVITY OF CRUDE PETROLEUM FROM VARIOUS PARTS OF THE WORLD

Sp. gr. > 0.95

Source	Sp. gr.
AFRICA	
Algeria.....	0.79 to 0.98
Egypt.....	0.83 to 0.97
Gold Coast.....	0.87 to 0.98
Ivory Coast.....	0.96
Sidi Braham.....	1.02
Tunis.....	0.97
ASIA	
Assam.....	0.86 to 0.98
Burma.....	0.81 to 1.00
Japan.....	0.80 to 0.98
Malay Archipelago	
Borneo.....	0.86 to 0.97

#### SPECIFIC GRAVITY OF CRUDE PETROLEUM.—(Continued)

Source	Sp. gr.
Java.....	0.81 to 0.97
Roengkoet.....	0.97
Persia.....	0.78 to 1.06
AUSTRALIA.....	0.84 to 0.97
New Zealand.....	0.84 to 0.97
EUROPE	
Galicja (Drohobycz).....	0.84 to 0.96
Germany.....	0.81 to 1.00
Greece.....	1.05
Hungary.....	0.80 to 0.98
Italy.....	0.75 to 0.97
Russia (Daghestan).....	0.85 to 0.96
NORTH AMERICA	
Canada.....	0.75 to 0.97
Cuba.....	0.73 to 0.96
Haiti.....	0.92 to 0.96
Mexico.....	0.79 to 1.06
United States	
Alaska.....	0.79 to 0.99
California.....	0.77 to 1.01
Louisiana.....	0.80 to 0.97
Oklahoma.....	0.79 to 0.88
Texas.....	0.80 to 0.97
Utah.....	0.83 to 0.95
Wyoming.....	0.80 to 1.00
SOUTH AMERICA	
Argentina.....	0.90 to 1.00
Barbados.....	0.88 to 0.97
Colombia.....	0.86 to 0.97
Ecuador.....	0.88 to 0.99
Peru.....	0.82 to 0.95
Trinidad.....	0.81 to 0.98



## SPECIFIC GRAVITY OF CRUDE PETROLEUM.—(Continued)

Source	Sp. gr.
Sp. gr. < 0.75	
EUROPE	
Italy.....	0.75 to 0.97
Russia (Caucasus).....	0.65
NORTH AMERICA	
Canada.....	0.75 to 0.97
Cuba.....	0.73 to 0.96
United States	
Pennsylvania.....	0.70 to 0.89

## STRAIGHT RUN PETROLEUM PRODUCTS (113)

Approximate specific gravity range at 15.5°C = 60°F

Product	Range
Paraffin-base Crude	
Cymogene (rare).....	0.588
Light petroleum ether.....	0.633–0.626
Heavy petroleum ether.....	0.654–0.639
Natural gas gasoline.....	0.675–0.622
Gasolene.....	0.747–0.709
Kerosene.....	0.816–0.797

## STRAIGHT RUN PETROLEUM PRODUCTS (113).—(Continued)

Product	Range
Mineral seal oil (300 burning oil).....	0.825–0.811
Gas oil.....	0.845–0.816
Non-viscous neutrals.....	0.865–0.850
Viscous neutrals.....	0.882–0.865
Paraffin oils.....	0.904–0.873
Paraffin wax.....	0.947–0.871
Red oils.....	0.910–0.904
Filtered cylinder stock.....	0.896–0.887
Bright stock.....	0.916–0.893
Steam-refined oils.....	0.928–0.898
Naphthene-base Crude	
Natural gas gasoline.....	0.702–0.669
Light gasolene (if any).....	0.720–0.702
Gasolene (if any).....	0.763–0.731
Kerosene (if any).....	0.825–0.816
Gas oil.....	0.876–0.855
Low pour test machine oil (low viscosity)....	0.928–0.922
Low pour test machine oil (medium viscosity)...	0.934–0.928
Low pour test machine oil (high viscosity)....	0.940–0.934
Black oil.....	0.947–0.940
Flux.....	0.986–0.973

## GASOLENE FRACTIONS (177)

Kind of gasolene	Sp. gr. of fraction. 15.5°/15.5°C = 60°/60°F						
	Fractionation temperatures						
	Up to 50°C	50° to 75°C	75° to 100°C	100° to 125°C	125° to 150°C	150° to 175°C	175° to 200°C
Eastern "straight" refinery	0.633 to 0.639	0.666 to 0.672	0.699 to 0.712	0.727 to 0.736	0.742 to 0.755	0.764 to 0.770	
Mid-Continent "straight" refinery.....	0.630 to 0.645	0.672 to 0.696	0.712 to 0.736	0.736 to 0.761	0.755 to 0.779	0.773 to 0.779	0.788 to 0.795
California "straight" refinery.....	0.639 to 0.645	0.678 to 0.693	0.723 to 0.739	0.752 to 0.764	0.773 to 0.788		
Blended casing head (eastern).....	0.624 to 0.633	0.663 to 0.675	0.703 to 0.715	0.733 to 0.739	0.752 to 0.761	0.767 to 0.776	0.782 to 0.785
Cracked (Mid-Continent).....	0.636 to 0.645	0.675 to 0.684	0.712 to 0.721	0.736 to 0.749	0.752 to 0.767	0.767 to 0.785	0.788 to 0.801

Blending Chart.—For use in determining % of naphtha to be added to gasolene to obtain blend of given density,  $v$ . (8).

## LUBRICATING OIL AT LOW TEMPERATURES

This sample had the following properties:  $S_{15.5}^{15.5} = 0.9427$ ; Fl. P., 224°C;  $\eta$  at 98.9°C, 92 sec Saybolt; Pour point, -18°C. The density data were  $d_4^t = 0.9740$ , (-35° to -40°C); and  $d_4^t = 0.9523 - 0.000665t$ , (-30° to +20°C) (76).

## PARAFFINS

*Solid*.— $d_{15}^{15} = 0.87 - 0.94$ ;  $d_{15}^{50} = 0.84 - 0.89$ . Recorded data on thermal expansion very conflicting, possibly due to enclosed air (19, 158, 166, 211). Between -190° and 17°C Dewar found  $\frac{1}{V} \frac{\Delta V}{\Delta t} = 0.000357$  per deg (43).

*Liquid*.— $d_{15}^{50} = 0.777 - 0.785$ ;  $d_{15}^{80} = 0.755 - 0.780$ .  $d_{15}^t = \text{const.} (= 53 \text{ to } 85) \times 10^{-5}t$  (between ca. 50° and 100°C) (19, 158, 166, 211).

## MISCELLANEOUS

*Petrolatum* ("Vaseline").— $d_4^t = 0.873$ , 23°; 0.868, 32°; 0.862, 42°C (206).

*Petroleum Ether*.— $V_t = V_0(1 + 146 \times 10^{-5}t + 16.0 \times 10^{-7}t^2)$ , -190° to 0°C (90).

## THERMAL EXPANSION

$$d_t = d_s - \alpha(t - t_s) + \beta(t - t_s)^2$$

$$\alpha = (66 \pm 5) \times 10^{-5}; \text{ for } S \leq 0.84$$

$$\alpha = [(189.4 - 146.5S) \pm 3] \times 10^{-5}; \text{ for } S > 0.84$$

$$\beta = [(-15.4 + 19S) \pm 2] \times 10^{-7}$$

$$d_t = d_4^t \text{ or } d_{15.5}^t$$

$$d_s = d_4^{t_s} \text{ resp. } d_{15.5}^{t_s} \text{ when } 15^\circ < t_s < 35^\circ$$

$S$  = the density or specific gravity (two decimal places sufficient) at any temperature between ca. 15° and 35°.

*Example*: Given  $d_{15.5}^{17} = 0.6935$ , to find  $d_{15.5}^{60}$   
 $d_{60} = 0.6935 - (189.4 - 146.5 \times 0.69) \times 10^{-5} \times (60 - 17) + (-15.4 + 19 \times 0.69) \times 10^{-7}(60 - 17)^2 = 0.6551 \pm \text{ca. } 0.0003$ .

For all practical purposes, the above relations appear to be applicable to all petroleum oils, both crude and refined, between 0° and 50°C (and probably to 100°C) as long as they continue to remain homogeneous liquids sufficiently fluid to be measured with a hydrometer (18). For elaborate computed tables convenient for temperature conversions and based substantially on the above relations  $v$ . (10, 41).

*Additional Literature on Thermal Expansion*.—Crudes (51, 94, 148, 182, 183, 197). Derivatives (94, 102, 117, 181).

*Expansion above 100°C*.—A recent investigation (225) of California petroleum products yields the equations:

$$v_t = v_{15.56} [1 + \alpha(t - 15.56^\circ) + \beta(t - 15.56^\circ)^2] \quad (\text{Range, } 15^\circ \text{ to } 260^\circ\text{C})$$

and

$$v_t = v_{260} [1 + \alpha'(t - 260^\circ) + \beta'(t - 260^\circ)^2] \quad (\text{Range, } 260^\circ \text{ to } 400^\circ\text{C})$$

$$\alpha = [2.32 - 1.7S] \times 10^{-3}; \text{ for } S \leq 0.82$$

$$\alpha = [4.36 - 4.2S] \times 10^{-3}; \text{ for } 0.82 < S < 0.75$$

$$\beta = [4.86 - 4.5S] \times 10^{-6}$$

$$\text{For } S = 1.0 \quad 0.95 \quad 0.90 \quad 0.89$$

$$10^3 \alpha' = 0.75 \quad 0.83 \quad 1.05 \quad 1.20$$

$$\beta' = [20.29 - 19.45 S] \times 10^{-6}$$

where  $v_t$  is the volume (cm<sup>3</sup>) at  $t^\circ\text{C}$ . and  $S$  is the specific gravity at 15°C.

## COMPRESSIBILITY

The mean coefficient of compressibility between  $P_1$  and  $P_2$  is defined by the equation

$$\beta = \frac{V_{P_1} - V_{P_2}}{V_{P_1}(P_2 - P_1)}$$

*Kerosene and Lubricating Oils.*—Within the accuracy of the measurements, all available data are correctly expressed by the equation

$$\frac{10^{-6}}{\beta} = a + bP - cP^2 + dP^3,$$

in which  $\beta = \frac{V_0 - V_P}{V_0 P}$  is the mean coefficient between 0 and  $P$ .

*Conversion Factors.*—To convert a pressure, in any of the following units, into atmospheres, multiply it by the factor given.

Megabarye	kg cm <sup>-2</sup>	Lb. in. <sup>-2</sup>
0.98692	0.96784	0.068047

*Kerosene.*—Between 1 and 11 atmospheres and 0–100°C,  $\beta$  in atm.<sup>-1</sup> is expressed by the equation  $\beta = (67.5 + 0.458t) \times 10^{-6}$  (161).

PARAFFIN (17)  
M. P. 55°C  $\beta = \frac{V_{20} - V_P}{V_{20}P}$

P atm.	10 <sup>6</sup> $\beta$ at t°C			
	64°	100°	185°	310°
20				
100	83	106	172	331
200	83	103	156	289
300	84	99	147	257
400	solid	94	137	236

$P$  in atmospheres. "Range" = pressure limits within which the equation may be used to calculate  $\frac{V_{P_1} - V_{P_2}}{V_{P_1}}$

Name of oil	t°C	10 <sup>3</sup> a	10 <sup>6</sup> b	10 <sup>12</sup> c	10 <sup>15</sup> d	Range atmospheres	$\frac{10^5(V_0 - V_{1000})}{V_0 \times 1000}$	Lit.
Kerosene.....	20	(13.05)	4.4175	160.24	5.114	2000–12 000	5.776	(1)
Kerosene.....	20	13.05	4.2059	135.94	3.687	0–12 000	5.839	(23)
Kerosene.....	40	11.60	4.2220	135.39	3.343	0–12 000	6.374	(23)
Kerosene.....	60	10.48	4.0379	113.69	2.484	0–12 000	6.941	(23)
Kerosene.....	80	9.55	3.8079	91.15	1.794	0–12 000	7.537	(23)
"Paraffin oil"*	34	12.0	4.631	280.6	24.3	0–4 300	6.107	(153)
Lubricating oils								
"F. F. F. cylinder".....	40	17.7	4.3	0.0	0.0	0–1 400	4.545	(95.1)
"Mobile A".....	40	17.4	4.3	0.0	0.0	0–1 400	4.608	(95.1)
"Mobile BB".....	40	18.0	4.3	0.0	0.0	0–1 400	4.484	(95.1)
"Victory red".....	40	18.9	5.0	0.0	0.0	0–1 400	4.184	(95.1)
"Bayonne".....	40	17.1	4.3	0.0	0.0	0–1 500	4.673	(95.1)

\*  $d_4^{20} = 0.812$ ;  $d_4^{34} = 0.785$ ; flash point 55°C.

## VISCOSITY

See also Lubricants and Lubrication, p. 164.

Viscosity Units and Their Interconversion. See vol. I, p. 25.

*Viscosity at Room Temperatures.*—Typical values in poises are:

- Gasolenes, 0.003–0.006;
- Kerosene, 0.02;
- Light lubricating oils, 0.025–1.5;
- Medium lubricating oils, 1.5–3.5;
- Heavy lubricating oils, 3.5–20;
- Petrolatum (M. P., 85°–95°F), 1.3 at 130°, 0.24 at 210°F.

*Variation of Viscosity with Temperature.*—If the viscosity of an oil is known at two temperatures, its viscosity at a third temperature may be obtained graphically with the aid of Fig. 1. When the viscosity temperature values for any oil are graphed on this chart a straight line will be obtained for all portions of the temperature range within which the oil remains a homogeneous liquid of constant composition (11). Copies of this chart may be obtained by addressing The Texas Company, New York City.

## SURFACE TENSION

Below are summarized the reported data on the surface tension ( $\gamma$ , in dynes per cm) of various products.

*Crudes.*—24–38 at 20°C (63, 84, 160, 176). The lower values, 24–26, are reported for crudes from Pennsylvania and California (176); the higher values, 35–38, for crudes from California fields at Montebello, Sunset, and Kern (84).

*Petroleum Distillates.*—For distillates up to 300°C,  $\gamma = 19$ –29 at 20° and is approximately a linear function of the density. See Fig. 12 (p. 157).  $d\gamma/dt = ca. -0.1$  per °C between 0° and 50° (63, 64, 140, 176)

*Naphthas.*—(B. P. up to 150°C).  $\gamma = 19$ –23 at 20° (176).

*Kerosenes.*—(B. P. 150°–300°C).  $\gamma = 23$ –32 at 20° (77, 176).

*Gas Oils.*— $\gamma = 28$ –29 (175).

"Gas Oil Distillates."—(150°–300°C).  $\gamma = 21$ –28 (175).

"Tar Oils."— $\gamma = 34$ –37.6 (175).

"Tar Oil Distillates."—(150°–300°C).  $\gamma = 27$ –36 (175).

*Lubricating Oils.*—Oklahoma and California.  $\gamma = 36$ –37.5 at 30°C (63, 78).

"Wax Distillates."— $\gamma = 34$ –36 at 30°C (63).

*Paraffin.*— $\gamma = 30.6$  at 54°C (162).

## INTERFACIAL TENSIONS

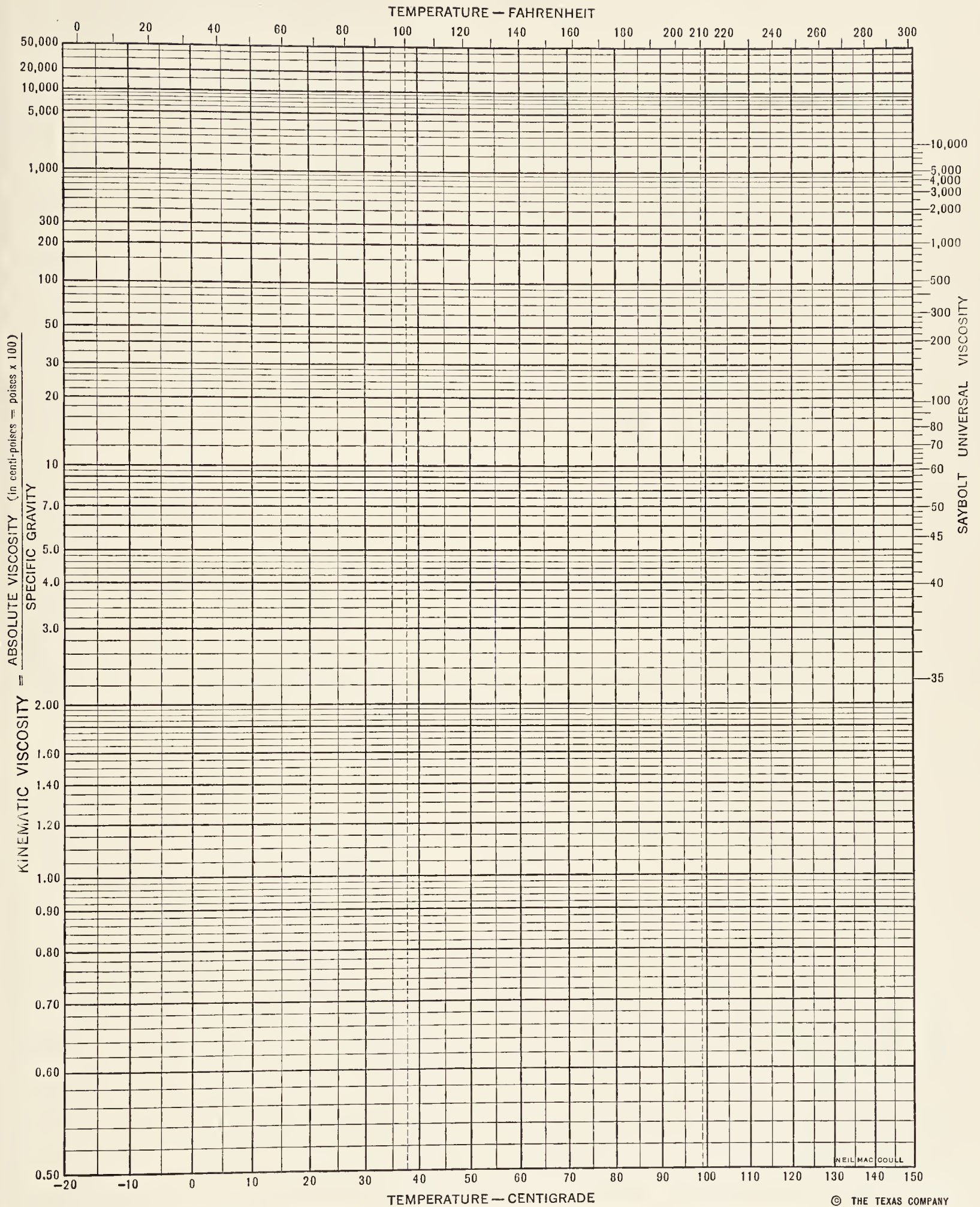
*Oil-Water Interface.*—Dyne cm<sup>-1</sup>. Gasolenes and naphthas, 39–51; kerosene, 47–49; mineral seal, 47–50; lubricating oils, 33–54; cylinder oils, petrolatum, paraffin at higher temperatures, 35–50, increasing after filtration. Several days' exposure to light produces decreases up to 30% (70, 99).  $d\gamma/dt = ca. -0.1$  between 4° and 8°C.

Addition of fatty acids lowers the interfacial tension against both H<sub>2</sub>O and Hg (20, 213).

## PENETRATIVITY (1)

The penetrativity,  $z$ , of a liquid is measured by the ratio  $\gamma/2\eta$  where  $\eta$  is the viscosity (206). If  $z$  for H<sub>2</sub>O is taken as 1 at room temperature,  $z$  for kerosene is 0.05 at 20°C;  $z$  for paraffin is 0.092 at 65°, 0.39 at 185° and 0.45 at 215°C.  $z$  for petrolatum ("vaseline") in absolute units is  $0.063(t - 30)^2$  cm sec<sup>-1</sup>, where  $t$  is the temperature in °C between 100 and 200.





# VISCOSITY---TEMPERATURE CHART

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PETROLEUM AND ITS PRODUCTS

FIG. 1.

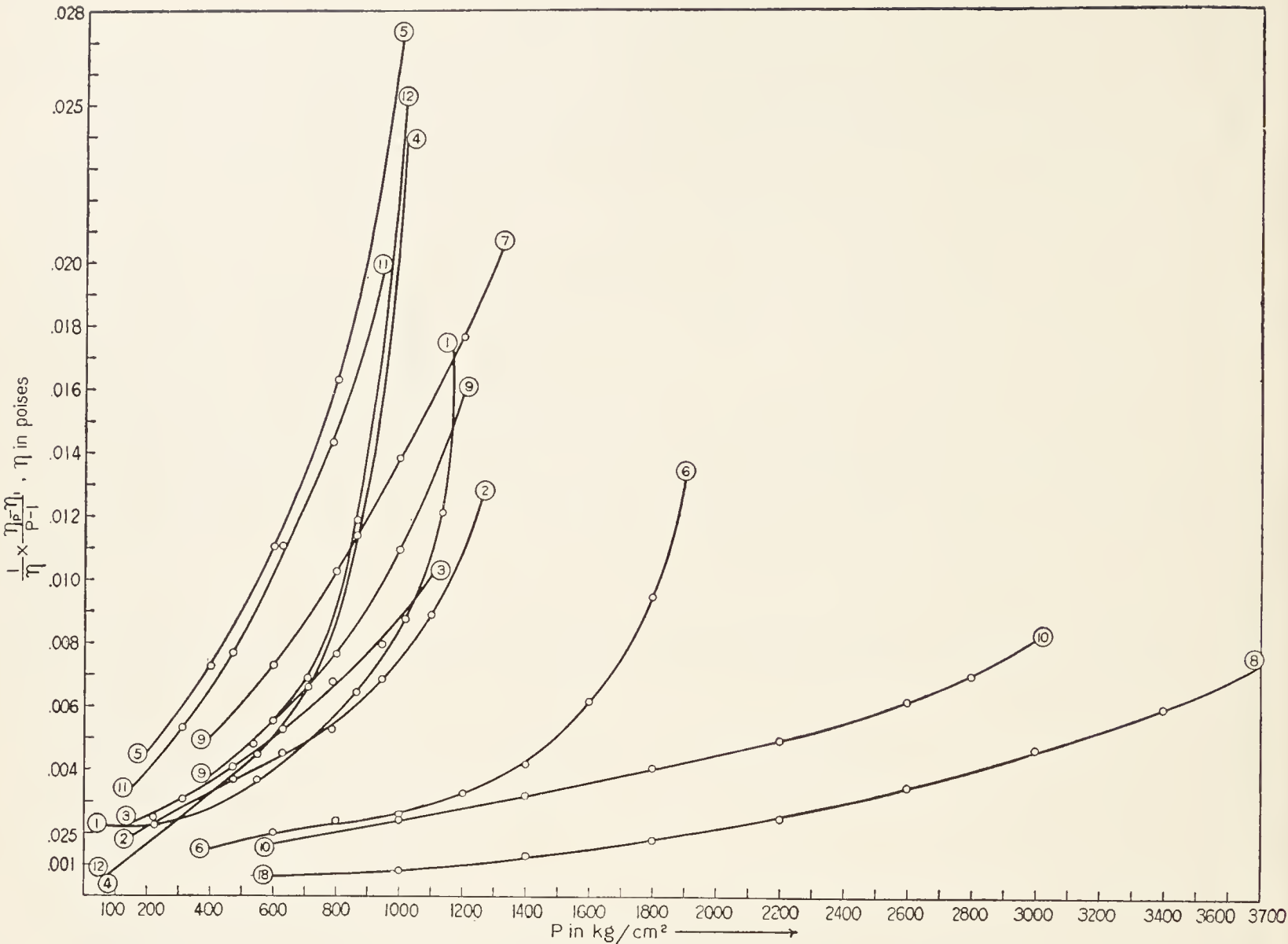


FIG. 2.—Variation of viscosity with pressure.

Curve No.	Designation of oil	t, °C	Lit.	Curve No.	Designation of oil	t, °C	Lit.
1	Mobiloil "A".....	40	(95)	7	Texaco.....	24	(85)
2	Bayonne: d <sub>15</sub> <sup>15</sup> 0.906; Fl. P. 191°C; η <sub>100</sub> 330 Saybolt; pour test 0°C.....		(95)	8	Texaco.....	100	(85)
3	F. F. F. cylinder: d <sub>15</sub> <sup>15</sup> 0.892; Fl. P. 260.0°C; η <sub>100</sub> 2400 Saybolt; pour test 5.6°C.....	40	(95)	9	Veedol.....	22	(85)
4	Mobiloil "B. B.".....	40	(95)	10	Veedol.....	100	(85)
5	Mobiloil "A".....	24	(85)	11	Victory red mineral: d <sub>15</sub> <sup>15</sup> 0.914; Fl. P. 183.9°C; η <sub>100</sub> 1140 Saybolt; pour test 2.8°C.....	40	(95)
6	Mobiloil "A".....	100	(85)	12	Mobiloil "B": d <sub>15</sub> <sup>15</sup> 0.908; Fl. P. 201.7°C; η <sub>100</sub> 390 Saybolt.....	40	(95)

MELTING POINT

The petroleum products of commerce are all mixtures, and consequently possess no sharp melting or freezing point; but exhibit instead a *melting range*. It is, of course, possible by suitable blending to obtain a product with almost any initial melting or freezing point between the extreme limits of -150°C (0.70 specific gravity gasolene) and +60°C (the high melting waxes).

*Typical Values.*—The limiting values recorded below show the regions of the temperature scale within which the melting or freezing ranges of some typical commercial products may be expected to lie (For "pour test" see p. 156).

Material	Typical melting or freezing range, °C
Gasolene 0.704 sp. gr. 15.5/15.5.....	-122 to -150
.719 sp. gr. 15.5/15.5.....	-120 to -147
Petroleum jelly—pale.....	39 to 51
Paraffin waxes:	
Match wax.....	40.5 to 46
White crude scale (Pa.).....	50 to 52.2
Semi-refined (Pa.).....	50 to 51
Fully refined (Pa.).....	49 to 50
Fully refined (Calif.).....	59 to 60
Ceresins:	
General range.....	60 to 80
Normal wax.....	65 to 66
Pure.....	79 to 80



### MELTING POINT OF PARAFFINS

Variation of melting point with oil content (221)

Material	% of pressed oil	Refractive index at 25°C	Melting point °C
"Parowax".....	0.16	1.4481	51.7
Refined wax.....	0.28	1.4487	50.0
Refined wax.....	0.25	1.4485	50.0
Refined wax.....	0.17	1.4481	51.7
Refined wax.....	0.16	1.4479	51.7
Refined wax.....	0.09	1.4476	54.4
Refined wax.....	0.08	1.4475	54.4
Scale wax.....	2.58	1.4570	48.3
Scale wax.....	2.56	1.4568	48.3

### Variation of Melting Point of Paraffin with Pressure

$t_P = t_0 + 0.029776 (P - 1) - 0.0000523 (P - 1)^2$ , between 1 and 200 atm.

$t_P$  (resp.  $t_0$ ) = melting point of paraffin under pressure  $P$  (resp. 1 atm.).

### SOLUBILITY OF PARAFFIN

For solubility of various kinds of paraffin in gasolenes, kerosene, lubricating oil, paraffin oil, fuel oil, benzene, alcohols, and acetic acid see (184).

### VAPOR PRESSURE AND BOILING POINTS

The few available data when graphed ( $\log p$  against  $1/T$ ) are found empirically to give approximately straight lines.  $p$  = the vapor pressures at  $T^\circ\text{K}$ . In the table below are given, (1) typical or limiting values of the B. P. (at 1 atm.) for the class, (or, in parentheses, the B. P. at 1 atm. as obtained by extrapolation of the vapor pressure curve); (2) the range covered by the available vapor pressure data; (3) the value of  $d \log_{10} p / d(1/T)$ , the slope of the vapor pressure curve; and (4) the source of the experimental data.

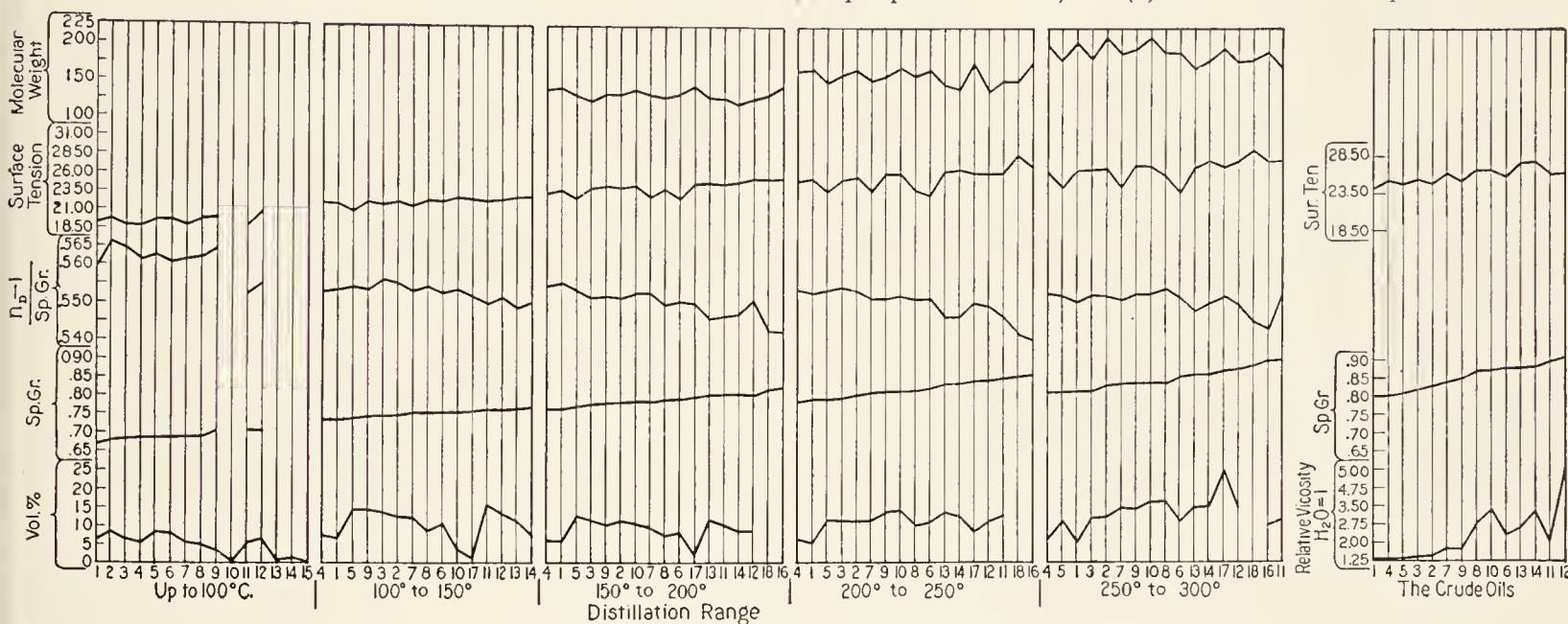


FIG. 3.—Comparison of the physical properties of petroleum distillates from different crudes (176).

### SOURCE OF CRUDE PETROLEUMS USED

1. Pa., Brandon, Pleasantville (580 ft.).
2. Okla., Collinsville.
3. Pa., Emlinton (1050 ft.).
4. Pa., Emlinton (1195 ft.).
5. Pa., Brandon, Pleasantville (650 ft.).
6. Calif., Piru Ventura Co.
- 7, 9, 10. Okla., Collinsville.

8. Okla., Healdton.
11. Calif., Piru, Ventura Co.
12. Calif., Santa Maria.
- 13, 14. Russia.
- 15, 16, 18. Calif., Midway, Kern Co.
17. Mexico.

### VAPOR PRESSURE DATA—PETROLEUM PRODUCTS

Designation of material	No. of samples	Normal B. P. °C	Pressure range mm Hg	$d \log_{10} p / d(1/T)$	Lit.
Gasolenes.....	6	93-198	30- 2 500	1600-1700	(25, 35, 45, 61, 171, 217, 218, 219)
Kerosene.....	1	215-255	50- 630	2230	(218, 219)
Kerosene.....	1	(240)	1800-30 000	3100	(42)
Gasoline.....	1	(63)	1800-30 000	1160	(42)
Paraffin-base oil.....	1	(315)	10- 100	1240	(222)
Transformer oil.....	1	200	300- 700	740	(33)
Vaseline.....	1	(215)	2000-16 000	2950	(42)
C <sub>6</sub> H <sub>6</sub> .....	1	80.5	160-40 000	1670	(44, 115, 217)
n-C <sub>19</sub> H <sub>40</sub> .....	1	330	130- 8 000	3600	(217)
Kerosene W. W.....	1	125	250- 3 000	860	(33)
Casinghead gasoline....	1	(48)	1000-13 000	1130	(33)
Gasoline.....	1	(81)	1000- 6 400	1320	(33)

See also (200, 215, 220).

*Correction of B. P. for Barometric Pressure.*—In the present state of our knowledge, it is necessary to know the slope of the  $\log p$ ,  $1/T$  curve for the particular type of product under examination (*i.e.*, the B. P. must be determined at two pressures), in order to be able to make this correction with any degree of certainty for pressures not close to 760 mm.

### DEW POINTS

*Definitions and Abbreviations.*—The temperature at which condensation begins, when a mixture of air and motor fuel is cooled, is called the *dew point*,  $t_D$ . The *dew-point index*,  $I_D$ , is the sum of the °C boiling points at the 10, 20, 50, 70, 90, and 100 % points of the 100 cc standard Engler distillation procedure. For °F it is one-half this sum. The 85% point,  $t_{85}$ , is the boiling point corresponding to the 85% point of the Engler distillation.

The following generalizations have been put forward.

Thirteen commercial gasolenes with  $I_D$  values ranging from 612 to 1025 give, when mixed with 15 parts of air by weight, values of  $t_D$  ranging from 10° to 88°C, the relation being

$t_D = [12 + 0.187 (I_D - 600)] \pm ca. 5^{\circ}\text{C}$  (79, 80, 218).

Thirteen commercial gasolenes with  $t_{85}$  values ranging from 115° to 210°C give values of  $t_D$  ranging from 10° to 88°C, the relation being

$t_D = [10 + 0.83 (t_{85} - 115)] \pm ca. 5^{\circ}\text{ to }10^{\circ}\text{C}$  (79, 80, 218).

An increase in the ratio of air to fuel lowers the  $t_D$  (79, 80). See Fig. 4. According to Stevenson and Stark (193) the dew point of any gasolene-air mixture may be accurately ( $\pm 2^{\circ}\text{C}$ ) obtained from the chart of Fig. 5. This chart is based upon the

Deppé end point for the particular gasolene under examination. For method of determining this end point, *v.* (193).

For another method requiring the determination of three empirical constants of the gasolene, *v.* (103).

FLASH POINT

*Definition.*—The *Flash point* (Fl. P.) of a liquid is an arbitrary ignition temperature of its saturated vapor. Its value depends very materially upon the apparatus and experimental procedure employed, as illustrated by the following tables:

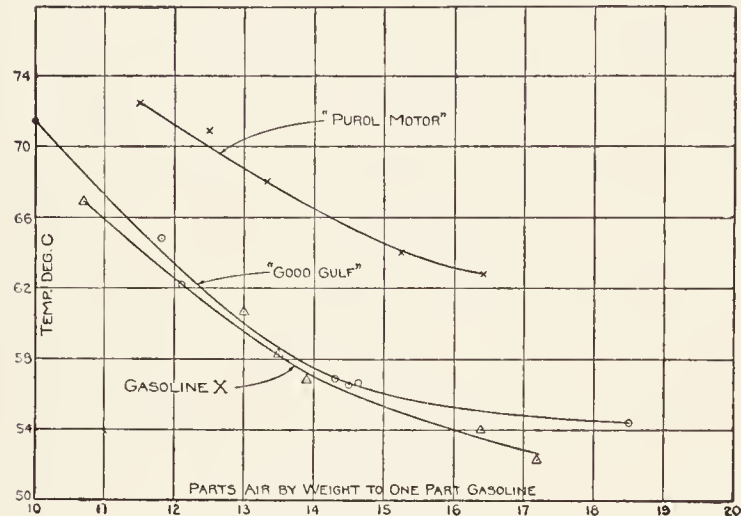


FIG. 4.—(Courtesy Industrial and Engineering Chemistry.)

The ratios for the curves are parts gasolene to parts air by weight.

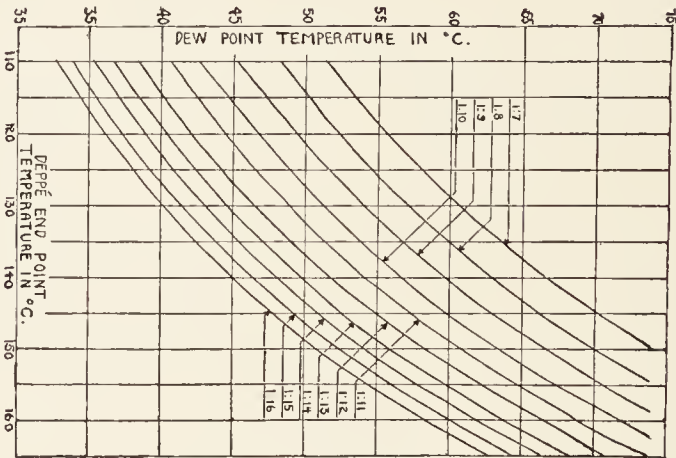


FIG. 5.—(Courtesy Industrial and Engineering Chemistry.)

COMPARISON OF FLASH TESTS BY DIFFERENT INSTRUMENTS

Type of oil (2)	Sp. gr.	°C		
		Treu- mann	Al- brecht	Pen- sky
Russian spindle.....	0.890	171.5	164.5	151
Russian machine.....	.908	211	199.6	193
Mixture of the above.....	.896	180.5	180	159
Wagon oil.....	.910	181	173.5	160
Locomotive oil.....	.912	185	182	170
Heavy machine oil.....	.916	236	207	202
Russian cylinder.....	.916		265	256

Type of oil (30)	Pensky Martens, °C	Open cup, °C
Mexican crude oil.....	19.0	35.0
Pechelbronn gas oil.....	26.2	34.0
Motor petrol.....	26.5	33.5
Diesel motor oil.....	58.0	82.0
Dried Pechelbronn crude .....	60.0	72.0
Motor oil.....	84.0	97.5
Cracking gas oil.....	85.0	95.0
Diesel motor oil.....	89.0	90.0
Tar oil.....	87.0	92.5
Residue.....	98.5	119.5
Heavy oil.....	101.0	110.0
Vaseline oil.....	175.0	177.0
Galician Diesel motor.....	128.0	177.0

Typical Values.—See Fig. 6.

COMPARISON OF FLASH TESTS BY DIFFERENT INSTRUMENTS

Material (39)	Abel, °C	Taglia- bue closed, °C	El- liot, °C	Pensky Martens, °C	Cleve- land open, °C	Luchaire (French), °C
Naphtha.....	30.0	33.3	33.3	35.0	37.8	37.8
Naphtha.....	34.4	39.4	36.7	40.6	46.1	50.0
Water-white kerosene...	52.8	54.4	53.3	57.2	60.0	58.9
Petrolite.....	61.1	59.4	60.0	65.6	68.3	62.2
Gas oil.....				90.6	93.3	92.2
300 oil.....				123.9	129.4	130.0
Straw oil....				157.2	162.8	161.1
Ice machine oil.....				204.4	196.1	205.6
Engine oil...				221.1	226.7	221.1
Cylinder oil..				262.8	273.9	263.9
Heavy cylin- der oil.....				265.6	293.3	265.5

Apparatus (53.1)	Kerosene, °C		
	A	B	C
Engler and Haass.....	22	29	40
Tagliabue open.....	31	42	52
Danish open.....	21	30	43
Saybolt open.....	31	36	51
Tagliabue closed.....	32		
Abel closed.....	17	23	33
Parish closed.....	21	27	38



**Variation with Barometric Pressure.**—If the logarithm of the barometric pressure is graphed against  $1/T_{Fl}$  where  $T_{Fl}$  is the absolute temperature of the Fl. P., a straight line is obtained, which apparently is parallel to the corresponding boiling point line for the same liquid. Few data are, however, available, *v.* (157). The correction of Fl. P. to standard barometric pressure is therefore made in exactly the same way as the correction for boiling point, *q.v.*

**Effects of Additions.**—(a) Addition of lower boiling hydrocarbons lowers the Fl. P. (15, 179, 212, 214). (b) Addition of halogenated hydrocarbons usually raises but in some instances lowers the Fl. P.  $C_2Cl_6$  and  $C_2H_4Br_2$  are among the compounds producing the greatest increase in Fl. P. (16, 210). (c) Addition of water raises the Fl. P.; 6°C for 1%  $H_2O$  being given in one instance (146).

**Relation between Fl. P. and Other Properties.**—(a) Specific gravity: For gasolenes the relation Fl. P. (°C) =  $800 \times (\text{sp. gr.} - 0.729) \pm \text{ca. } 2^\circ$ , agrees with the data of (195). See also (156). Boiling point, *v.* (48, 49, 94).

**Fire Point.**—The literature cited above contains a few values for fire points.

**Mixtures.**—For method of calculating the Fl. P. of a mixture from the Fl. P. of its constituents, *v.* (83).

**Pure Liquids.**—See p. 161.

°F →	0.0	100	200	Paraffin Oils				500	600
		Open Cup		Neutrals	Red			Filtered Cylinder & Bright Stocks	Steam Refined Stocks
				Low Vis	High Vis	Oils			
		Gas Oil						Pensky-Martens	
Gasoline		Kerosene						Closed Cup	
				PARAFFIN BASE PRODUCTS					
				NAPHTHENE BASE PRODUCTS					
Gasoline		Kerosene						Closed Cup	
		Gas Oil						Pensky-Martens	
				Red and Pale Oils Low (Med) High Vis				Open Cup	
°C →	-178	37.8	93	149	204	260	316		

FIG. 6.—Average flash point range of petroleum oils.

#### IGNITION TEMPERATURES IN HIGH PRESSURE AND LOW PRESSURE OXYGEN

Material	Fl. P. °C	Ignition temperature, °C	
		1 atm.	33 atm.
Sperm oil.....	236	308	140
Lard oil.....	240	273	144
Castor oil.....	263	325	153
Glycerine.....		412	205
Kerosene.....	55	255	175
Spindle oil.....	194	248	178
Turbine oils.....			253-291
Compressor oil, A.....		309	188
Compressor oil, B.....	196	273	187
Compressor oil, C.....	216	286	157

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#### THERMAL CONDUCTIVITY AND DIFFUSIVITY

$$\begin{aligned}
 k &= A \times 10^{-6} \text{ cal cm}^{-2} \text{ sec}^{-1} (\text{°C, cm}^{-1})^{-1} \\
 &= 4.18 A \times 10^{-6} \text{ joule cm}^{-2} \text{ sec}^{-1} (\text{°C, cm}^{-1})^{-1} \\
 &= 0.806 A \times 10^{-6} \text{ BTU}_{60} \text{ ft.}^{-2} \text{ sec}^{-1} (\text{°F, in.}^{-1})^{-1}
 \end{aligned}$$

Designation of material (M. P. and sp. gr.)	t°C	A	Lit.
Paraffin.....	-198	828	(59)
Paraffin.....	-78	887	(59)
Paraffin.....	0.0	688	(59)
Paraffin.....	20	285	(147)
Paraffin, 50.4°.....	0.29	372	(209)
	0.34	473	(209)
Paraffin, 66°, 0.92.....	23	640	(97)
Paraffin, 54°.....	0.14	571	(155)
Paraffin.....	0-31	558	(155)
Paraffin, 84°.....	0-13	608	(155)
Paraffin, 84°.....	0-26	584	(155)
Paraffin, 84°.....	0-33	564	(155)
Paraffin, 84°.....	22-48	489	(155)
Paraffin, 84°.....	21-57	470	(155)
"Paraffinöl," M. P. < -20°	0-29	331	(209)
	0-34	368	(209)
Cylinder oil.....	81	290	(58)
"Vaseline".....		440	(110)
Kerosene.....	0-29	368	(209)
	0-34	403	(209)

Designation of material (M. P. and sp. gr.)	t°C	$\alpha = d_k/d_t$ per °C	Lit.
Paraffin.....		+0.0634 (?)	(207, 208)
Paraffin.....	10-45	-0.0076	(107)
Kerosene.....		+0.011	(75)

Diffusivity =  $\frac{k}{c \times d} = 10^{-6} B \text{ cm}^2 \text{ sec}^{-1}$ , where  $c$  = specific heat and  $d$  = density. For kerosene at 13°C,  $B = 890$  (75).

#### SPECIFIC HEAT

A recent critical examination ((36) *q.v.* for bibliography) of all the available data for animal, vegetable and mineral oils together with many new determinations shows that the data for all types of oils are well represented by the following equation:

$$c_p = \frac{A}{\sqrt{d_4^{15}}} + B(t - 15) \text{ g cal/g,}$$

where  $d_4^{15}$  is the density at 15°C and A and B are constants characteristic of the class to which the oil belongs, as shown by the following table and Fig. 7.

Oil	No. of samples	A	Av. dev. ±	Max. dev. ±	10 <sup>3</sup> B	Av. dev. ±	Max. dev. ±
Paraffin base.....	15	0.425	0.002	0.004	0.90		
Naphthene base...	7	0.405	0.002	0.004	0.90		
Mixed base.....	8	0.415	0.002	0.004	0.90		
Fatty, non-drying.	7	0.450	0.001	0.002	0.70		
Fatty, semi-drying	1	0.445			0.70		
Fatty, drying.....	1	0.440			0.70		
Castor.....		0.500			0.70		
Petroleum oils....	30	0.415	0.007	0.013	0.90	0.03	0.06
Fatty oils (except castor).....	9	0.450	0.003	0.010	0.70	0.03	0.05

#### Latent Heat of Fusion

Paraffin, 35-39 g cal/g (72).

#### Latent Heat of Vaporization

Recorded data mostly fragmentary. In the following summary, the values given are calories per gram: 1 cal g<sup>-1</sup> = 1.800 BTU<sub>60</sub> lb.<sup>-1</sup>; 10 gasolenes, 71-81; 2 kerosenes, 60; 1 light crude, 75.6; 1 heavy crude, 86; 1 gas oil, 69; 1 light "vaseline," 63; 1 heavy "vaseline," 54; 1 "cleaning oil," 66.5 (73, 152, 170).

One investigation of a series of 12 petroleum fractions with boiling points ( $t_B$  °C) ranging from 67° to 300°, gives the following:

$$l = (93.4 - 0.187t_B) \text{ cal g}^{-1} \text{ at } t_B \text{ (114) cf. (152).}$$

Investigation (81) of a series of fractions of Baku petroleum gave:

Sp. gr.....	0.640	0.698	0.743	0.762	0.797	0.813
$t_B$ °C.....	40	72.8	92.2	100.7	155.7	175.5
$l$ , cal/g.....	80.6	75.0	68.3	66.6	53.6	51.6

### CALORIFIC VALUES

The heats of combustion,  $H$ , (at constant volume, to produce liquid water and gaseous  $\text{CO}_2$ ) of petroleum products can be very

satisfactorily represented as a linear function of their specific volumes, the parameters of the equation varying slightly according to the type of product. The equation may be conveniently written in the form

$$H = A + B\left(\frac{1}{d} - 1\right),$$

where  $H$  is the heat of combustion per gram,  $d$  is the density in  $\text{g cm}^{-3}$ , and  $A$  and  $B$  are constants. From the data reported in the literature the constants  $A$  and  $B$  have been evaluated and the results are set forth below.

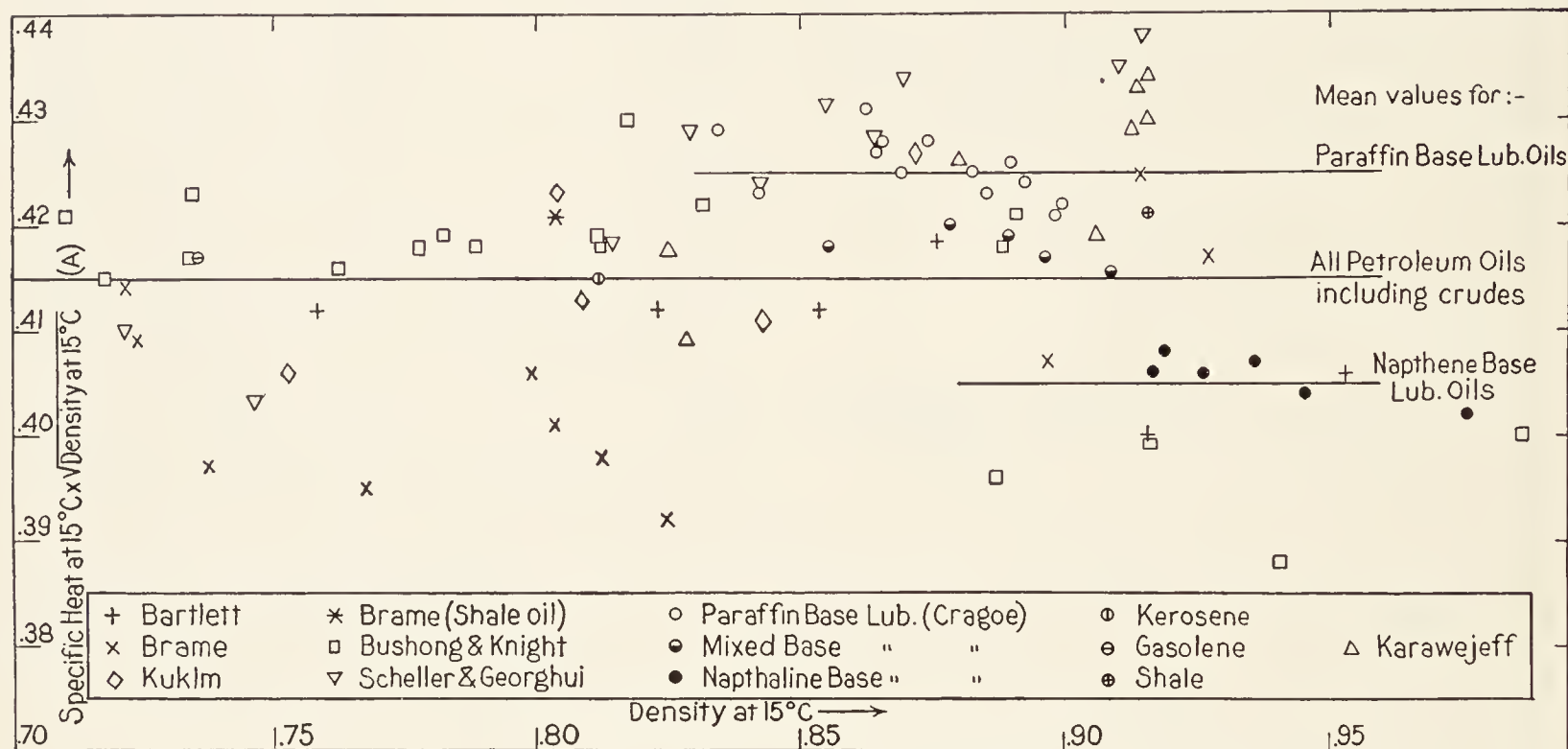


FIG. 7.—Specific heat of petroleum products.

$$1 \text{ kg-cal}_{15} \text{ g}^{-1} = 1800 \text{ BTU}_{60} \text{ lb.}^{-1} = 4.185 \text{ kJ g}^{-1}$$

Type	No. of samples	$H = A + 4\left(\frac{1}{d} - 1\right)$ kg-cal per g	Dev. $H_{\text{obs.}} - H_{\text{calc.}}$			
			Average		Maximum	
			Plus	Minus	Plus	Minus
Crudes (6, 7, 31, 39, 74, 104, 154, 183, 185, 189, 198, 223).....	164	10.14	0.08	0.11	0.77	0.19
Distillates						
$d$ from 0.67 to 0.75.....	44	9.69	.17	.25	.77	.67
$d$ from 0.75 to 0.85.....	41	10.03	.16	.21	.95	.83
$d$ from 0.85 to 0.90.....	83	10.20	.07	.10	.21	.70
$d$ from 0.90 to 0.97.....	38	10.30	.12	.08	.45	.25
(5, 22, 28, 31, 34, 39, 96, 118, 151, 154, 164, 167, 170, 177, 189, 196, 223).						
"Lubricating oil" (190) ....	3	10.27	.02	.01	.02	.03
Coal tar oils (32).....	8	9.69	.15	.09	.24	.18
Coal tar oils (223).....	3	10.02	.03	.06	.06	.06

For the following products density data were not available and the values given are  $H$  in kg-cal  $\text{g}^{-1}$ .

Paraffin..... 11.09 and 11.17 (194).

Ozokerite..... 10.65 and 10.95 (141, 183).

Coal tar oil..... 9.94 and 10.22 (96, 154).

### REFRACTIVE INDEX

The function  $\frac{n_D - 1}{d}$ , where  $n_D$  is the refractive index for the D line (approximately daylight) and  $d$  is the density, both at the same temperature, is approximately a constant for all types of petroleum products, varying between the extreme limits of 0.53 and 0.61. For a set of distillates from a given crude the value of this function for the crude and for all of its distillation fractions is apparently constant within 1 to 3%. In the table below are shown for various types of products (1) the number of samples included in the average; (2) the average and extreme values of  $\frac{n_D - 1}{d}$  at room temperatures, or similar values of  $n_D$  for samples for which  $d$  values were not available.



Designation of product	No. of samples	$\frac{n_D - 1}{d}$			Lit.
		Low	Av.	High	
Crudes.....	17	0.530	0.554	0.567	(54, 62, 112)
Ligroin.....	1		0.552		(199, 203)
Benzine.....	13	0.531	0.557	0.567	(62, 199, 203)
"Turpentine substitute"...	3	0.54	0.558	0.57	(199, 203)
Naphtha.....	4	0.558	0.560	0.563	(62, 203)
Gasolene.....	23	0.557	0.566	0.577	(62, 112, 203)
Kerosene.....	11	0.553	0.556	0.563	(62, 112, 199, 207)
"Gas oil".....	4	0.554	0.556	0.558	(62)
Pressure distillate.....	2	0.563		0.564	(62)
Mineral oils.....	4	0.562	0.563	0.564	(178)
Liquid paraffin (Ph. G.)...	5	0.542	0.543	0.543	(203, 68)
Wax distillate.....	3	0.560	0.565	0.608	(62)
Distillation fractions for various intervals of each of the total ranges given.					
140°-310°C.....	20	0.543	0.556	0.572	(50)
40°-300°C.....	50	0.556	0.559	0.578	(111)
195°-282°C.....	10	0.555	0.557	0.557	(26)
50°- 60°C.....	1		0.562		(159)
340°-350°C.....	1		0.581		(159)
		Values of $n_D$			
Petroleum ether.....	1		1.375		(203)
Mineral oil.....	2	1.478		1.498	(91)
Spindle oil.....	2	1.477		1.489	(168, 203)
Lubricating oil.....		1.478		1.517	(94)
Machine oil.....	1		1.498		(203)
Petroleum jellies—"vaseline," at 15°C.....	7	1.471	1.474	1.498	(203)

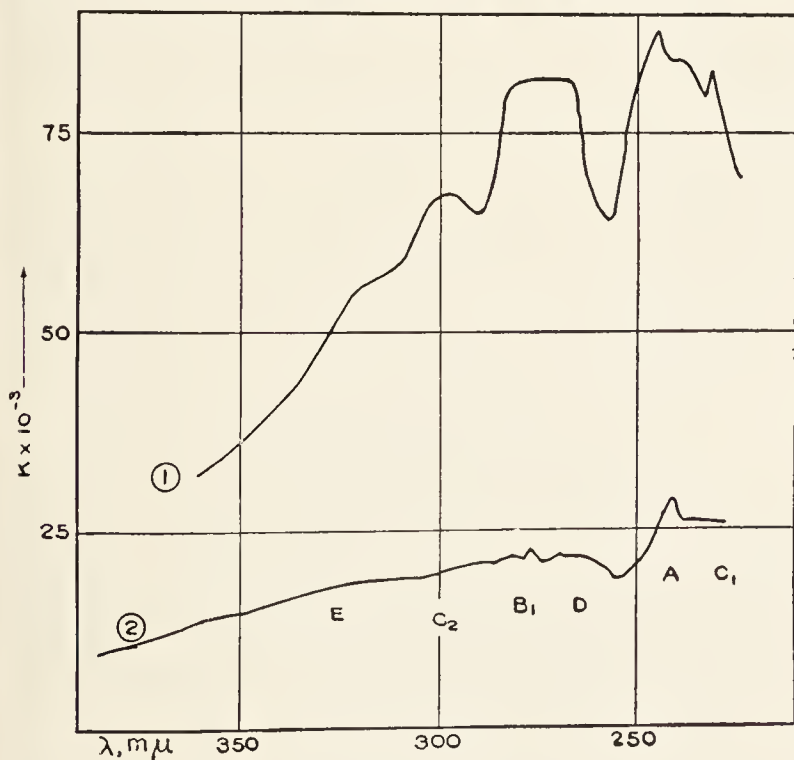


FIG. 8.

**Paraffins and Mineral Waxes.**—Recorded data on  $n_D$  at various temperatures between 15° and 100° for 35 samples with melting points from 36° to 61°C, range from 1.415 to 1.446, density data on the samples unfortunately not being given (29, 65, 68, 168, 203). For 3 ozokerite samples, 40°-90°,  $n_D$  = 1.42 to 1.53 (68). For 16 ceresin samples, M. P. 57°-73°,  $t$  = 15° to 100°C,  $n_D$  1.426 to

1.454 (29, 68, 168, 203).  $\frac{dn_D}{dt}$  = -0.00039 to -0.00043 per °C for paraffin; -0.00047 per °C for ceresin (68, 221).

**Effect of Acid Washing.**—For effect of washing and filtering on  $n_D$  of petroleum distillates *v.* (62, 132).

### OPTICAL ACTIVITY

Most petroleum products contain optically active constituents. The reported values of the specific rotatory power  $[\alpha]_D$  (*v. vol.* I, p. 41) range from -1° to +9° of arc per decimeter per (g per cm<sup>3</sup>), the lower value being reported for a 134-142°C boiling point (11.5 mm Hg) fraction from a Roengkoet crude (53.1) and the higher value for a 216°C B. P. fraction from an Argentine (Mendoza) crude (57). For detailed data *v.* (52, 53, 53.1, 56, 57, 164, 192, 224).

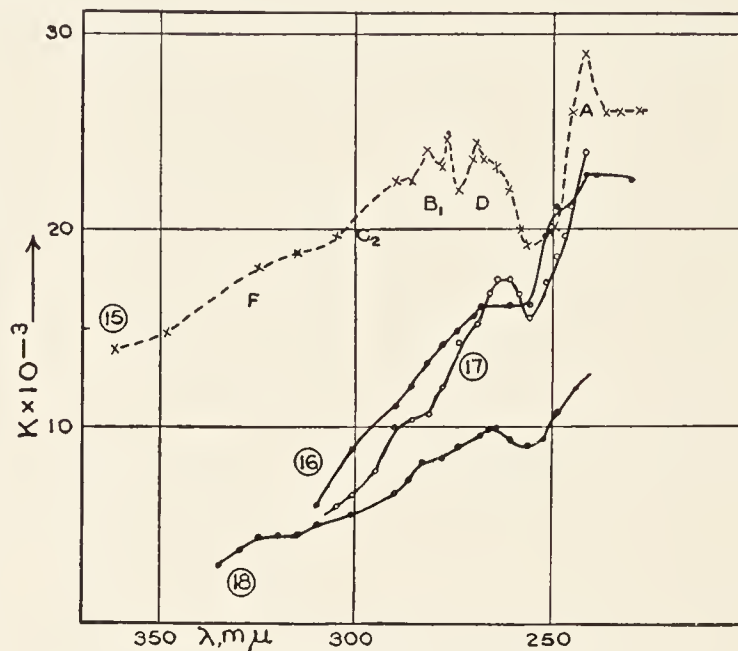


FIG. 9.

### COEFFICIENT OF LIGHT ABSORPTION (204)

In Figs. 8, 9, 10, 11, the coefficient of light absorption,  $K$ , of various petroleum products in solution in chloroform is graphed against the wave lengths in millimicrons.

$$K = \frac{\log \frac{J_0}{J}}{Cl}$$

where  $J_0$  (resp.  $J$ ) = intensity of initial (resp. emergent) radiation,  $C$  = concentration of the oil in  $\text{CHCl}_3$  in g/cm<sup>3</sup>, and  $l$  = absorption thickness. In the various experiments the quantity  $1/Cl$  was varied between 50 and  $4 \times 10^4$ .

### DESIGNATION OF OILS

Num-ber	Oil	Num-ber	Oil
1	Tar	10	Crude kerosene
2	Dry crude petroleum oil	11	Cleaning oil
3*	Crude petroleum oil	12	Rectified kerosene
4	Crude gasolene	13	Refined kerosene
5	White spirit (gasolene)	14	White spirit
6	Heavy gasolene	15	Dry crude petroleum oil
7	Light rectified gasolene	16	Crude machine oil
8	Light refined gasolene	17	Refined machine oil
9*	Crude petroleum oil	18	Crude paraffin

\* For these curves, multiply the ordinates by 330.

## IODINE AND BROMINE NUMBERS

("Olefins," "unsaturation")

Values reported range over wide limits and "type characteristic" values apparently do not exist. Time, temperature, concentrations of reagents, and other test conditions influence the results obtained. The original literature must be consulted. In the following summary I = iodine No., Br = bromine No.

*Crudes.*—Br, 0.6 to 17 (53.1); I, 0.0 to 15 (53.1, 98, 185, 104).

*Distillates.*—Br, 0.5 to 95 (4, 53.1, 98, 144, 202); I, 0.0 to 100 (53.1, 61, 69, 71, 94, 98, 163, 177).

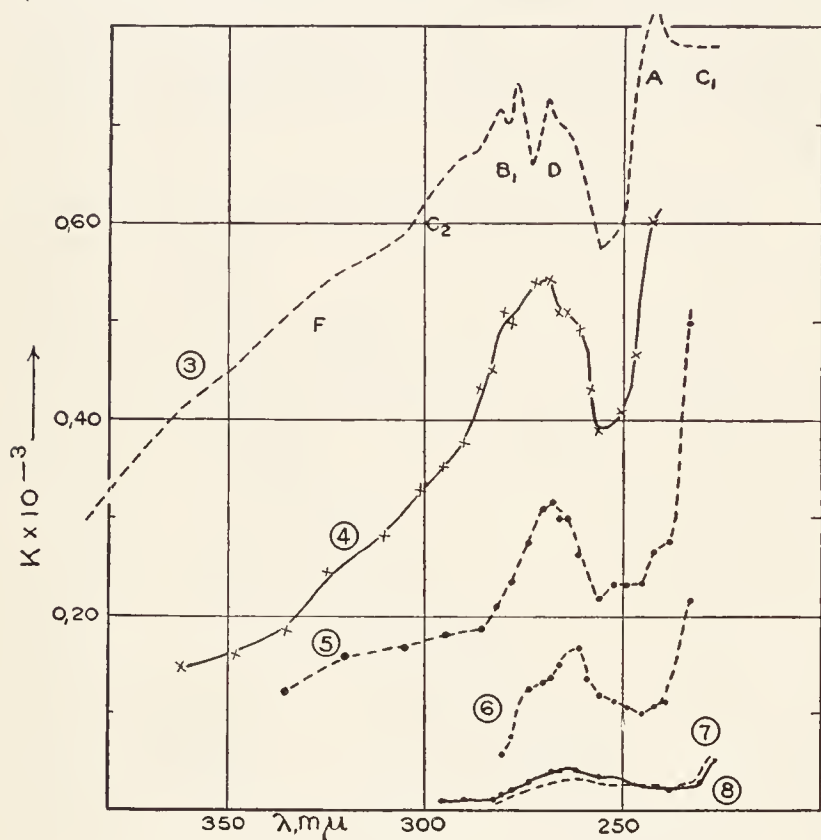


FIG. 10.

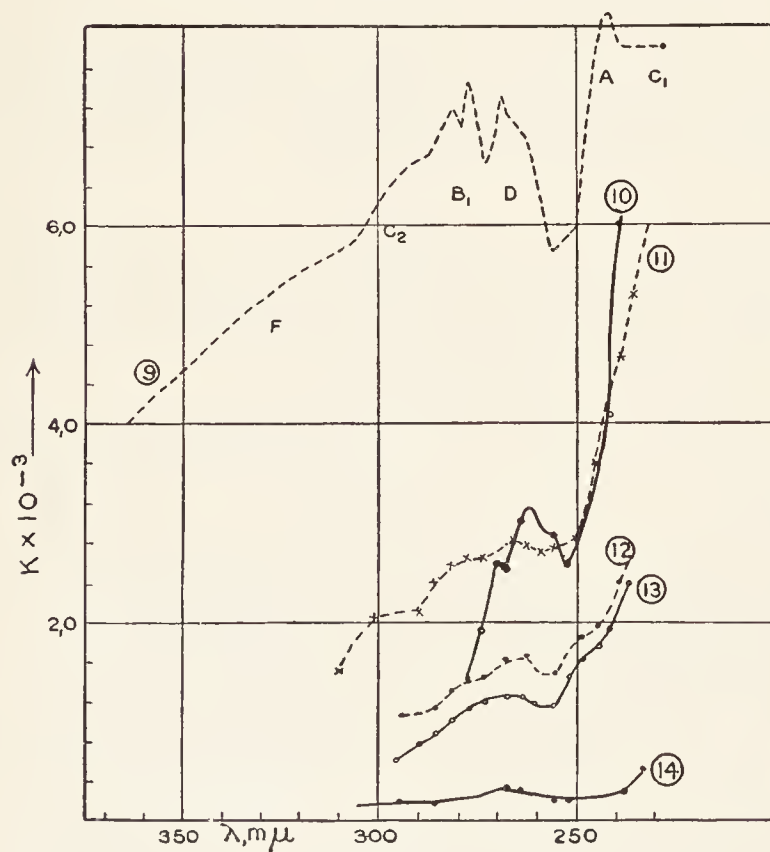


FIG. 11.

*Lubricating Oils.*—Br, 0.0 to 56 (4, 144); I, 0.4 to 57 (15, 53.1, 163, 185).

*Waxes and Jellies.*—Br, 0.5 to 20 (4, 144); I, 0.4 to 21 (3, 15, 46, 60, 71, 86, 98, 100, 101, 116, 163, 180, 191).

*Transformer Oils.*—(163).

*Bibliography.*—(98).

*Some Sample Values.*—The following values are by one observer, using the Hanus method, but with  $\text{CCl}_4$  as the solvent for the halogen. A = "addition value," S = "substitution value" (98).

## IODINE AND BROMINE VALUES OF TYPICAL PETROLEUM PRODUCTS

	Grams used	Iodine value			Bromine value		
		A	S	A+2S	A	S	A+2S
Pentane.....	1	0.37		0.37	0.39	0.06	0.51
Straight run naphtha.....	1	0.53	1.58	3.69	0.65	1.55	3.75
Straight run naphtha (treated).....	1	0.47	1.14	3.29	0.64	1.44	3.52
Cracked naphtha.....	1	14.70	8.16	31.02	9.39	4.62	18.63
Cracked naphtha (treated)...	1	10.72	8.48	27.68	6.80	5.65	18.10
Straight run lamp oil distillate.....	1	1.32	5.04	11.40	0.69	3.13	6.95
Straight run lamp oil distillate (treated).....	1	0.74	5.06	10.86	0.48	3.00	6.48
Cracked lamp oil distillate...	0.5	23.23	9.52	42.27	21.81	7.57	36.95
Cracked lamp oil distillate (treated).....	0.5	17.59	10.63	38.85	16.42	8.57	33.56
Straight run gas oil.....	1	2.56	9.62	21.80	2.44	3.93	10.30
Cracked gas oil.....	1	4.59	14.26	33.11	4.45	7.22	18.89
Lubg. stock (uncracked).....	1	0.83	12.06	24.95	2.09	5.83	13.75
Lubg. stock (uncracked, filtered).....	1	0.32	11.48	23.28	1.55	5.78	13.11
Lubg. stock (from run to coke).....	1	0.85	14.43	29.71	3.55	9.48	22.51
Lubg. stock (from run to coke, treated).....	1	0.42	13.32	27.06	1.39	7.17	15.73
26½ cylinder stock (Pa.)....	1	2.29	10.99	24.27	1.76	6.43	14.62
26½ cylinder stock (filtered)...	1	0.21	11.67	23.55	0.64	6.56	13.76
Petrolatum stock.....	1	11.31	7.26	25.83	6.93	3.10	13.13
Petrolatum stock (filtered, U. S. P.).....	1	1.76	11.31	24.38	2.43	4.40	11.23
Refined paraffin wax (132° M. P.).....	1	1.10		1.10	1.16	2.25	5.66
Amorphous wax from petrolatum (165° M. P.).....	1	1.32	2.90	7.12	1.38	1.50	4.38
White medicinal oil.....	1	0.05		0.05	0.40	1.90	4.20
86-88 gasolene.....	1	1.74	0	1.74	0.58	0.34	1.26
70 gasolene.....	1	1.20	0	1.20	0.83	0.05	0.93
Motor gasolene.....	1	5.91	2.73	11.37	3.71	1.15	6.01
V. M. & P. naphtha (55°Bé)...	1	2.00	2.51	7.02	1.47	1.10	3.67
Varnoline (51°Bé).....	1	2.63	3.36	9.3	1.49	0.85	3.19

## SULFURIC ACID ABSORPTION FOR GASOLENE

("Unsaturation," "olefins")

The reported data are mostly not systematically obtained and methods are ill-defined. In one investigation (40), however, 43 samples of gasolene were investigated both as to iodine No. (Hanus) and % absorption by 1.84 sp. gr.  $\text{H}_2\text{SO}_4$ . The I numbers ranged from 47 to 293 and the acid absorption from 8 to 46, the ratio showing an average value of 6.5 with 7.5 as maximum and 5.3 as minimum. For discussion of reaction between olefins and  $\text{H}_2\text{SO}_4$  see (24).

## GUM TEST

(37, 92, 93, 106, 187) and also (67), which contains a bibliography.

## COMBINED PROPERTY TABLES

In this section are given, for comparison purposes, tables displaying values of several properties determined on the same sample of oil. In most instances these are expressed in the units given by the investigator.



Crude Petroleums  
CALIFORNIA PETROLEUMS, AVERAGE VALUES  
For values of *all* the samples examined, *v.* (6).

District	$d_{15}^{15}$	Open cup		Viscos- ity at 20°C Engler	H <sub>2</sub> O %	S %	Volume per cent							
		Flash point °C	Burn- ing point °C				Naph- tha unre- fined	Fuel oil	Gaso- lene re- fined	Lamp oil re- fined	Lubri- cants re- fined	Re- fining losses	Dis- tilling losses	Asphal- tum (com- mercial)
Los Angeles City.....	0.963	107	145	272.5	1.7	0.6	0.0	98.3	0.0	4.5	32.1	12.5	0.6	48.6
La Brea, Salt Lake or Santa Fe	0.960	46	89	574.3	0.9	2.3	0.0	99.1	0.0	13.0	22.3	9.6	0.9	53.3
Fullerton.....	0.921	18	52	110.5	0.2	0.9	0.3	99.5	0.3	21.7	24.1	10.3	1.3	42.1
Brea Canyon.....	0.923	11	40	16.0	Tr.	0.9	0.1	99.9	0.1	23.1	24.5	10.9	1.2	40.2
Pucnte Hills.....	0.891	-2	18	3.1	Tr.	0.4	0.8	99.2	0.8	32.3	23.1	10.3	1.2	32.3
Whittier.....	0.939	46	84	34.6	0.0	0.6	0.0	100.0	0.0	17.1	30.1	12.6	0.6	39.6
Coyote Hills.....	0.905	27	50	10.5	Tr.	1.1	0.0	100.0	0.0	18.2	26.4	10.4	1.0	44.0
Newhall.....	0.925	60	83	118.2	0.2	0.4	0.1	99.7	0.1	23.0	27.7	10.8	6.8	37.3
Piru.....	0.914	23	47	47.0	0.2	0.7	0.4	99.4	0.4	21.7	28.1	11.1	0.6	37.9
Bardsdale.....	0.918	-1	30	22.5	4.2	1.9	1.8	94.0	1.8	16.7	25.7	9.8	0.7	41.1
Sespe.....	0.895	18	40	10.8	0.4	0.3	1.1	98.5	1.1	22.0	27.5	10.8	1.2	37.0
Santa Paula.....	0.902	6	18	5.8	0.5	0.5	1.2	98.3	1.2	25.4	27.2	10.9	0.7	34.1
Adams Canyon.....	0.920	38	55	11.3	Tr.	0.6	0.0	100.0	0.0	17.7	30.6	11.8	0.7	39.3
Wheeler Canyon.....	0.888	-12	2	2.3	0	0.5	1.3	98.7	1.3	28.6	25.4	9.9	1.0	33.8
Summerland.....	0.965	100	130	222.1	1.2	0.4	0.0	98.8	0.0	1.2	39.8	14.7	0.5	42.6
Santa Maria.....	0.905	-2	20	19.0	0.1	1.9	2.0	97.9	2.0	26.1	22.5	9.2	1.5	38.6
Lompoc.....	0.934	-1	21	62.5	0.7	3.6	0.0	99.3	0.0	17.6	18.4	7.5	1.1	55.3
Arroyo Grande.....	0.975	109	154	1322.2	0.2	1.1	0.0	99.8	0.0	0.0	29.1	11.2	0.4	59.1
Coalinga.....	0.939	70	93	80.7	0.4	0.5	0.0	99.6	0.0	7.6	37.2	14.2	0.5	40.1
Midway.....	0.932	54	83	91.7	0.6	0.7	0.0	99.4	0.6	15.9	33.5	13.2	0.7	36.1
Sunset.....	0.942	47	79	120.5	0.5	0.8	0.3	99.2	0.3	14.6	30.3	11.8	0.9	41.6

## RUMANIAN PETROLEUMS

Source	Sp. gr. 15/15 °C	Boiling point limits °C	Wt. % dist.	Sp. gr.	% paraffin		Elementary analysis wt. %					Specific heat cal g <sup>-1</sup>	Vis- cosity centi- poises	Hübl- Waller iodine No.	Acid- ity as SO <sub>3</sub>	Treat- ing loss*
					Dist.	Crude	C	H	O	N	S					
Moinești.....	0.869	80-150	8.9	0.730	10.64	5.04	85.8	13.1	0.35	0.28	0.44		13	7.7	0.04	48.0
		150-300	33.8	0.814												
		>300	57.3													
Bustinari.....	0.842	75-150	26.6	0.737	0.77	0.25	86.0	13.3	0.29	0.31	0.15	0.463	5.8	3.7	0.17	30.0
		150-300	32.7	0.821												
		>300	40.7													
Campina, rich in paraffin.	0.855	85-150	12.6	0.738	7.30	3.18	85.1	13.7	0.81	0.24	0.15	0.468	8.4	5.3	0.07	34.0
		150-300	36.7	0.815												
		>300	50.7													
Campina, poor in paraffin	0.869	87-150	12.7	0.739	1.71	0.76	86.3	12.5	0.77	0.27	0.2	0.467	13.1	6.5	0.18	48.0
		150-300	34.7	0.825												
		>300	52.6													
Filipești.....	0.853	91-150	17.2	0.725	11.60	4.97	86.6	13.0		0.29	0.17		5.6	27	0.007	29.0
		150-300	33.1	0.809												
		>300	49.7													
Policiori.....	0.829	94-150	9.9	0.750	13.92	4.6	85.8	12.2	1.55	0.27	0.15	0.472	4.4	1.7	0.007	18.5
		150-300	53.6	0.813												
		>300	36.5													
Moreni.....	0.888	73-150	14.8	0.746	0.67	0.29	86.4	10.2	2.79	0.30	0.24		22	5.9	0.34	47.5
		150-300	29.6	0.844												
		>300	55.6													
Baicoi.....	0.881	56-150	23.8	0.743	0.41	0.16	85.7	12.9	0.85	0.30	0.2		11	8.8	0.25	72.0
		150-300	25.0	0.841												
		>300	51.2													

\* Loss on shaking 4 parts 66° H<sub>2</sub>SO<sub>4</sub> and 1 part oil for 15 minutes at 25°C (185).

## VARIOUS CRUDE PETROLEUMS

Source	$d_{15}^{15}$	Flash point °C	Viscosity		Amount of distillate, vol. %			Residue vol. %
			Eng- gler°	t°C	to 130°C	130- 270°C	270- 300°C	
California.....	0.962	82	4.3	80			32	68
Coalinga.....	0.958	111	3.1	80			31	69
Argentina.....	0.940	124	13.6	80			24	76
Peru.....	0.865	<15			21	29	9	41
Pennsylvania...	0.805	<15			12	50	13	25
Mexico.....	0.934	24	11	15	7	38	31	24
Texas.....	0.944	120	34	20		16.8	12.2	71
Sumatra.....	0.792	<0				50.5	4	11.5
Rumania.....	0.854	<15			20	35	7	38
Wietze.....	0.942	105	15	50		11.9	8.8	79.3
			4.7	80				
Alsace (upper layer).....	0.880	<15			5	22	7	66
Russia.....	0.873	38				40	13	47
Galicia.....	0.862	<15			20	45	11	24
			Sec		to 175°	175-300°	300-360°	
Argentina (119)...	0.96	41	350.6	50	3.4	12	17	62.7

## Hydrocarbon Oils (154)

Designation	$d_{15}^{15}$ (* = $d_{18}^{18}$ )	% composition				Open cup	
		C	H	S	O and N	Flash °C	Fire °C
Fuel oil.....	0.921	85.3	11.9	0.6	2.2	133	164
Crude.....	.923			0.5		125	155
Light fuel.....	.900*	88.6	10.8	0.4	0.2	187	220
Admiralty fuel.....	.928	86.4	11.6	0.3	1.7	138	163
Residuum.....	.943*	86.4	11.2	0.3	2.0	166	197
Black oil.....	.928	86.4	11.8	0.5	1.2	144	172
Refined oil.....	.904*	85.1	12.2	0.4	2.4	122	135
Rumanian crude.....	.825			0.2		Room	
Rumanian crude.....	.830	83.8	13.0	0.3	3.0	Room	
Texas solar.....	.862*	85.4	12.9	0.2	1.6	92	97
	.855*	86.2	12.4	0.3	1.2	129	158
Scottish shale oil...	.862	85.4	12.4	0.3	1.7	130	150
	.867			0.3		130	148
Gas oil.....	1.067	87.6	6.0	0.7	5.7	90	109
Gas oil.....	1.004	83.7	7.3	0.8	8.2	77	86

## Hydrocarbon Oils (29)

Source	$d_{15}^{15}$	B. P. Range °C	Index of ref. $n_D^{15}$	Rieke and Halphen sol. index	Crit. diss. temp. in alc., °C	Turbidity temp. in acetic anhy- dride, °C
Naphtha fractions						
American.....	0.780	— to 191	1.4345	93	50	78.5
American.....	0.800	191 -227	1.4453	117	68.5	91
American.....	0.820	227 -266	1.4563	154	87	104.5
Russian.....	0.780	— to 158.5	1.4309	75	36	66
Russian.....	0.800	158.5-182	1.4419	85	47.5	72
Russian.....	0.820	182 -219.5	1.4533	92	60	79.5
Rumanian.....	0.780	— to 153	1.4334	73	Clear	53
Rumanian.....	0.800	153 -179	1.4458	79.5	30	57
Rumanian.....	0.820	179 -207.5	1.4572	90.5	42	63.5
Galician.....	0.780	— to 166	1.4356	74	31	60
Galician.....	0.800	166 -202	1.4466	94	53	75.5
Galician.....	0.820	202 -242	1.4586	125.5	72.5	89.5
Shale.....	0.780	— to 167.5	1.4373	74	31	54.5
Shale.....	0.800	167.5-198	1.4469	92.5	42.5	63
Shale.....	0.820	198 -227.5	1.4568	109	54	71
						Solidi- fication
Russian spindle....	0.894	198	1.4888		150	< -15
American cylinder.	0.891	255	1.4950		194	0

## Typical Lubricating Oils

Average values representative of one large manufacturer.  
Other companies may produce products whose  
tests vary widely from those listed below

Specific gravity 60/60°F	Cleveland O. C.		Saybolt viscosity		Pour point °F	N. P. A. color
	Flash °F	Fire °F	70°F	100°F		

## NEUTRAL OILS

0.843	275	325	45		25	1
0.849	285	330	50		25	1
0.854	325	375	70		25	1
0.859	330	385	65	70	25	1½
0.862	350	405	87	85	25	1½
0.864	375	425	105	100	25	2
0.867	380	435	120	110	25	3
0.870	395	450	130	120	25	3
0.872	400	455	150	140	25	4-5
0.875	410	475	185	165	25	5
0.878	420	485	200	180	25	6

## WESTERN "NEUTRALS"

0.883	370	430		140	30	3
0.889	375	435		170	25	3
0.892	385	440		200	25	3
0.895	390	450		230	25	4
0.897	395	455		250	25	4
0.900	400	460		280	25	5

## PARAFFIN OILS

0.870	325	380	70	65	30	2½
0.875	330	385	80	70	30	2½
0.878	345	400	85	80	30	2½
0.881	350	405	90	85	30	2½+
0.886	355	410	105	100	35	2½+
0.892	375	430	180	155	35	3
0.897	395	450	205	180	35	3
0.900	400	460	250	210	40	4
0.903	410	480	310	250	40	5
0.909	415	485	350	280	40	6
0.912	420	490	370	290	40	6+

## NAPHTHENE BASE. GULF COAST\*

0.924	295	335	100		0	2½
0.927	320	365	200		0	3+
0.930	340	400	300		0	3+
0.933	350	410	360		0	3+
0.933	360	415	500		0	3½+
0.937	385	440	750	60	0	3½+

## CALIFORNIA\*

0.921	295	345	100		0	3
0.927	310	350	150		0	3
0.933	330	365	205		0	3½
0.940	350	390	400		0	4
0.943	365	415	450		0	4½
0.946	380	430	850		0	6

## CYLINDER STOCK PENNSYLVANIA, BRIGHT, COLD-SETTLED\*

0.892	535	600		140	45	FF
0.897	540	605		152	40	FFF
0.900	545	610		168	40	FFF

\* Viscosities at 100° and 210°F.



## GAS OILS AND DERIVED TARS AND THEIR DISTILLATES (175)

All data for 20°C unless indicated otherwise. Charge for distillations 400 cc

	Gas oil No. 1				Gas oil No. 2				Gas oil No. 3				Gas oil No. 4			
$d_{15.5}^{15.5}$	0.872				0.858				0.872				0.890			
Surface tension $\gamma$ (dyne per cm)...	28.60				28.40				28.54				28.91			
Viscosity (specific).....	2.3								2.1				6.8			
Temperature, °C	Vol. %	$d_{15.5}^{15.5}$	$\gamma$	$n_D^{20}$	Vol. %	$d_{15.5}^{15.5}$	$\gamma$	$n_D^{20}$	Vol. %	$d_{15.5}^{15.5}$	$\gamma$	$n_D^{20}$	Vol. %	$d_{15.5}^{15.5}$	$\gamma$	$n_D^{20}$
150	0.9	0.790	22.40	1.416	1.3	0.788	22.22	1.419	1.1	0.759	21.59	1.412	0.8	0.775	23.38	1.426
200	1.5	0.800	24.30	1.434	1.1	0.798	24.29	1.442	2.2	0.778	23.79	1.434	3.1	0.794	24.32	1.437
225	1.1	0.809	25.57	1.441	2.0	0.814	25.97	1.448	2.3	0.799	25.22	1.448	4.8	0.815	25.36	1.446
250	4.2	0.818	26.28	1.454	5.6	0.824	26.87	1.453	3.0	0.817	26.23	1.455	6.4	0.832	26.43	1.454
275	5.4	0.836	27.60	1.464	6.2	0.832	27.41	1.458	6.1	0.837	27.18	1.464	6.8	0.845	27.07	1.462
300	12.2	0.849	28.12	1.472	8.0	0.842	27.86	1.464	9.9	0.851	28.06	1.472	9.5	0.853	27.67	1.469
Mixed distillate.....	25.4	0.837	27.16	1.463	24.2	0.828	26.90	1.458	24.6	0.830	25.77	1.462	31.4	0.833	26.60	1.458

	Tar oil No. 1				Tar oil* No. 2				Tar oil* No. 3				Tar oil No. 4			
$d_{15.5}^{15.5}$	1.071				1.090				1.122				1.086			
Surface tension $\gamma$ (dyne per cm)...	33.83				34.83				36.55				37.6			
Viscosity (specific).....	4.04				11.86				10.9				5.60			
Temperature, °C	Vol. %	$d_{15.5}^{15.5}$	$\gamma$	$n_D^{20}$	Vol. %	$d_{15.5}^{15.5}$	$\gamma$	$n_D^{20}$	Vol. %	$d_{15.5}^{15.5}$	$\gamma$	$n_D^{20}$	Vol. %	$d_{15.5}^{15.5}$	$\gamma$	$n_D^{20}$
150	1.9	0.870	27.49	1.491	0.8				1.2				3.1	0.874	27.44	1.499
200	4.4	0.903	29.44	1.520	0.9	0.940	30.26	1.531	1.6	0.942	30.28	1.532	7.0	0.916	29.13	1.529
225	6.5	0.940	30.95	1.541	1.1	0.956	32.44	1.562	3.1	0.977	33.66	1.557	6.9	0.956	30.69	1.553
250	11.2	0.975	32.39	1.569	4.2	0.984	33.31	1.576	6.5	1.012	35.21	1.572	11.4	0.986	32.16	1.576
275	8.2	0.983	32.61	1.572	12.3	0.993	33.51	1.582	10.8	1.027	35.69	1.585	10.5	0.998	32.84	1.587
300	7.2	0.995	32.95	1.579	6.0	1.010	33.79	1.589	6.3	1.047	36.08	1.594	5.8	1.018	33.25	1.597
Mixed distillate.....	39.4	0.970	31.95	1.562	25.3	0.983	32.20	1.578	29.5	0.968	34.10		44.7	0.968	31.66	1.566

\* Much difficulty was experienced in distilling tar oils Nos. 2 and 3, owing to the presence of water.

## Typical Lubricating Oils.—(Continued)

Specific gravity 60/60°F	Cleveland O. C.		Saybolt viscosity		Pour point °F	N. P. A. color
	Flash °F	Fire °F	100°F	210°F		

## MID-CONTINENT, BRIGHT, COLD-SETTLED

0.961 | 510 | 570 | | 145 | 45 | Lt. D.

## TEXAS, BRIGHT (NAPHTHENE BASE)

0.921 | 535 | 600 | | 150 | 30 | 6

## FILTERED CYLINDER STOCK (STEAM-REFINED)

0.881	450	525		90	75	
0.886	505	570		100	90	D
0.889	520	590		135	80	D
0.892	540	625		140	75	E
0.897	550	640		150	60	E

## UNFILTERED CYLINDER STOCK (STEAM-REFINED).

\* = MID-CONTINENT

0.897	550	615		140	35	
0.900	555	620		150	35	
0.903	560	625		160	40	
0.906	575	645		185	40	
0.909	590	660		200	35	
0.912	600	690		240	40	
0.915	625	710		575	50	
0.921	645	730		290	50	
*0.915	510	570		140	50	
*0.915	535	600		175	50	
*0.927	525	605		180	40	

Continued on p. 158

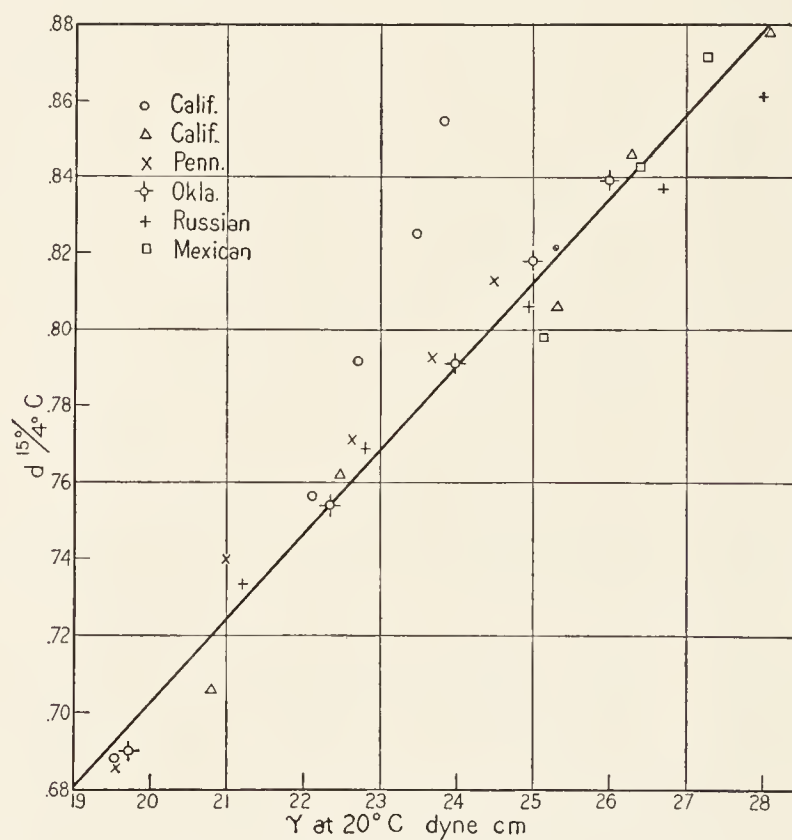


FIG. 12.—Variation of surface tension of petroleum distillates with density.

For comparison of the physical properties of petroleum distillates from different crudes see Fig. 3 (p. 149).

## Typical Lubricating Oils.—(Continued)

Specific gravity 60/60°F	Cleveland O. C.		Saybolt viscosity		Pour point °F	N. P. A. color
	Flash °F	Fire °F	100°F	210°F		
BLACK OILS						
0.881	320	370		35	20	
0.886	350	400		50	10	
0.895	375	425		60	15	
0.897	400	450		80	35	
0.915	420	470		100	30	

## Various Lubricating Oils (105)

Bk = Black; Bl = Blue; Br = Brown; G = Green; O = Orange;  
R = Red; t = Translucent; W = White; Y = Yellow

Designation	Source	$d_{15}^{15}$	Solid- ifica- tion point °C	Flash point °C Pensky Martens closed cup	Viscosity Engler °		Color
					25°C	50°C	
LIGHT LUBRICATING							
Vaseline oil.....	Russia	0.870	< -30	150	4.5		W
Medium spindle..	Russia	0.890	< -30	155	5.3		Y
Heavy spindle....	Russia	0.900	< -20	180	9.0		Y
Thin spindle.....	Penn.	0.865	- 3	155	3.0		Y
Average spindle..	Penn.	0.875	- 1	185	5.0		Y
MEDIUM LUBRICATING							
Machine.....	Penn.	0.890	0	195	8.0	3.2	R-Y
Machine.....	Penn.	0.917	3	205	16.0	4.6	G-R-t
Machine.....	Lima	0.921	- 2	205	16.5		G-R
Machine.....	Germany	0.920	5	170	17.0	4.9	G-R
Machine.....	Russia	0.909	< -15	195	14.0	4.2	O
Machine.....	Texas	0.932	< -15	175	14.5	4.4	G-R-t
Arctic.....	Penn.	0.878	2	200	7.6		G-R-t
Arctic.....	Lima	0.907	25	180	7.3		G-R-t
Turbine.....	Penn.	0.878	- 5	210	16.2		G-R-t
HEAVY LUBRICATING							
Machine.....	Russia	0.910	< -15	195	27.0	6.3	O-R
Machine.....	Russia	0.913	< -15	200	36.0	8.0	Br-R
Machine.....	Germany	0.925	< -15	185	24.8		O
Machine.....	Germany	0.940	- 5	190	27.0	6.3	Bl-t
Machine.....	Texas	0.932	- 5	185	26.0	6.1	Br-R
Machine.....	Texas	0.936	-18	185		7.0	G-t
Machine.....	Texas	0.946	- 9	195		8.7	G-t
Machine.....	Germany	0.932	- 8	180	35.4		G-t
Machine.....	Texas	0.940	-20	180	26.5		G-t
Machine.....	Texas	0.946	- 8	200		13.6	G-t
Machine.....	Texas	0.950	- 7.5	205		14.3	G-t
DARK LUBRICATING							
Winter.....	Russia	0.910	< -20	160	37.0	8.0	Bk-G
Summer.....	Russia	0.914	-12	155	50.9	11.0	Bk-G
Winter.....	Germany	0.927	< -20	155	16.5	5.0	Bk-Br
Summer.....	Germany	0.952	-10	185	440	9.6	
BRIGHT STEAM CYLINDER							
					50°C	100°C	
Cylinder.....	Penn.	0.884	34	260	15.0	2.9	G-R
Cylinder.....	Penn.	0.886	30	275	23.0	3.5	G-R
Cylinder.....	Penn.	0.890	10	290	26.0	4.0	G-R
Cylinder.....	Russia	0.913	-15	220	12.0	2.3	Bl-R
Cylinder.....	Russia	0.915	- 5	235	15.0	2.9	Bl-R
Cylinder.....	Texas	0.955	- 5	215		2.7	G-R
DARK STEAM CYLINDER							
Cylinder.....	Penn.	0.895	5	280	29.0	4.0	G-Bk
Cylinder.....	Penn.	0.903	3	295	40.0	5.0	G-Bk
Superheated steam oil.....							
Cylinder.....	Penn.	0.905	0	325	60.0	7.0	G-Bk
Cylinder.....	Russia	0.928	0	280	30.0	4.1	G-Bk
Cylinder.....	Russia	0.928	0	255	50.0	6.0	G-Bk
Cylinder.....	Germany	0.950	7	270	27.0	3.8	G-Bk
Cylinder.....	Texas	0.954	-11	230		3.2	

LUBRICATING OIL FROM BLENDS OF STOCKS FROM CUSHING AND  
BINBY CRUDES (62)

Sp. gr.	Cleveland open cup		Viscosity 100°F seconds Saybolt universal	Cold test °F	Color N. P. A.	$n_D^{20} - 1$ Sp. gr.
	Flash °F	Fire °F				
0.889	390	450	102	25	3	0.554
.889	395	440	100	23	3	.555
.887	350	405	95	24	2.5	.554
.896	400	430	184	26	3	.555
.895	405	445	172	26	4.5-	.555
.897	410	465	185	26	4	.556
.897	400	445	189	26	4.5+	.556
.897	395	445	180	24	4.5-	.556
.899	410	465	185	24	4.5-	.556
.899	400	445	198	26	5+	.557
.900	390	440	178	32	6-	.555
.900	400	460	196	25	6-	.555
.897	410	450	227	26	3-	.556
.902	405	465	246	28	4-	.555
.902			237	28	5+	.557
.903	415	470	227	28	6+	.557
.903	420	460	236	26	5+	.556
.901	410	460	226	28	Q	.557
.904	405	465	239	30	Q	.558
.904	410	460	250	34	6-	.558

Lubricating Oils for Internal Combustion Engines.—Oils designated by manufacturers' trade names. Sp. gr., flash and fire point, solidification temperature, viscosity at three temperatures, color, % distillation under 300°C, oxidation oven test (164.1).

## Steam Turbine Oils (188)

Viscosity Engler°		$d_4^{15}$	Iodine No. Hübl- Waller	$n_D^{20}$	Resinification index		
20°C	50°C				150°C	120°C	
					Tar	Coke	Tar

## OILS OF GOOD QUALITY

8.80	2.60	0.875	14.2	1.4828	0.44	0.50	0.13
9.08	2.66	.876	12.8	1.4826	.37	.17	.12
9.1	2.61	.876	11.7	1.4814			.11
9.78	2.66	.904	5.8	1.5020	.68	.63	.24
10.8	2.81	.883	0.4	1.4795	2.10	0	1.05
13.8	3.32	.900	7.1	1.4965	.74	.82	0.37
19.3	4.08	.908	8.5	1.5034	.84	1.02	.39
22.5	4.32	.904	4.3	1.4940	.64	0.92	.39
31.7	6.4	.874	10.4	1.4826	.46	.57	.29

## OILS OF POOR QUALITY

20.9	4.73	0.873	10.4	1.4822	0.65	0.92	0.23
25.4	4.57	.905	3.9	1.4965			
28.7	5.13	.907	4.6	1.4948	.63	.79	.38
30.0	5.28	.905	6.1	1.4949	.82	1.10	.62
13.1	3.20	.904					.30

## A "GOOD OIL"

9-14	0.870-0.905						0.2
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## Petroleum Oils for Diesel Motors (31)

$d_{15}^{15}$	Galicja	Germany	Rumania	Russia	N. America	Mexico	So. America	India	Japan
	0.86-0.89	0.725-0.94	0.89-0.95	0.876-0.95	0.865-0.95	0.86-0.97	0.85-0.99	0.89-0.95	0.92-0.96
Flash °C (Pensky Martens) .....	53-155	< -15 to 175	87-162	53-138	82-166	32-132	-10 to 144	92-150	131-164
Fire °C.....	77-170	< -15 to 203	106-194	78-180	103-200	58-162	-6 to 199	120-174	176-211
Residue dist. above 400°C, vol. %.....	0.0-3.9	0.2-15.0	1.0-23.0	1.5-11.5	2.2-16.5	0.3-23.0	4.0-21.0	0.0-4.9	2.5-15.0
Water %.....	0.0-0.8	0.0-9.8	0.0-0.8	0.0-0.0	0.0-3.3	0.0-9.56	Tr.-8.94	0.0-0.12	0.0-0.15
Ash %.....	0.0-0.4	0.0-0.6	0.0-0.2	0.0-0.16	0.0-0.4	0.0-0.64	0.01-0.17	0.0-0.03	0.0-0.19
Combustible %.....	>98.8	>90	99	99.8	>96	>89.8	>90.9	99.8	99.8
C %.....	85.6-86.9	85.1-86.8	86.5-87.4	86.1-87.5	84.2-86.9	83.0-85.1	85.5-87.0	86.5-87.7	87.0-88.0
H %.....	12.0-13.1	11.6-11.4	11.3-12.1	11.3-12.9	11.3-13.1	12.8-13.0	10.8-12.8	11.1-12.5	11.0-11.7
(O + N) %.....	0.1-1.2	0.0-1.2	0.6-1.5	0.5-0.9	0.2-2.0	0.5-1.7	0.9-1.8	0.2-1.0	0.2-1.0
S %.....	0.1-0.8	0.1-1.2	0.2-0.6	0.2-0.4	0.1-2.5	1.6-4.3	0.2-1.3	0.2-1.2	0.2-1.0
H per 1000 C.....	137-151	113-169	127-140	128-150	129-151	130-150	123-148	125-143	124-134
Coke %.....	0.21-1.0	0.5-5.6	1.11-3.8	0.9-3	1.9-6.4	0.14-10.9	1.9-6.7	0.0-4.7	0.8-5.4
Asphalt %.....	0.0-0.01	0.0-8.5	0.0-1.9	0.0-0.8	0.0-8	0.0-19.15	0.17-14.9	0.33-7.90	0.09-1.46
Heat of combustion kg-cal/kg									
Net { Crude.....	9.95-10.9	8.93-10.4	9.78-9.99	9.80-10.2	9.29-10.1	8.49-10.1	9.0-10.1	9.81-10.0	9.74-9.97
Water-free oil.....	10.0-10.2	9.87-10.4	9.78-9.99	9.81-10.2	9.6-10.1	9.37-10.1	9.72-10.1	9.81-10.0	9.74-9.97
Gross.....	10.7-10.9	10.5-11.1	10.4-10.6	10.4-10.86	10.3-10.8	10.1-10.8	10.3-10.8	10.4-10.7	10.3-10.6
Engler viscosity.....									
20°C.....	1.65-2.96	5.24-136	18.1-114	3-149	5.3-11	1.62-317		10.4-14.8	12-302
35°C.....								4.1-5.5	5.0-64
50°C.....	1.23-1.56	2.04-17.7	3.56-13	1.6-15	2.06-2.58		43-205	3.0-2.45	2.7-27
75°C.....							20-42		
100°C.....	1.02-1.13	1.26-2.43		1.14-2.40	1.23-1.38	1.03-4.47	6.3-13	1.22-1.37	1.3-2.5

## Tar Oils for Diesel Motors (32)

Source of tar	Coke oven	Water gas	Oil gas	Coal tar oil	Oven retorts		Vertical oven retort		Chamber oven
					Horizontal	Inclined	Dessau	Woodall-Duckham	
$d_{15}^{15}$ .....	1.14-1.18	0.97-1.13	1.05-1.07	1.0-1.11	1.15-1.23	1.12-1.16	1.06-1.12	1.08-1.10	1.06-1.09
Flash point °C (Pensky Martens).....	90-135	34-91	18-69	66-121	67-92	52-78	49-75	41-52	35-71
Fire point °C.....	108-166	50-ca. 155	20-89	84-160	93-129	79-107	70-102	71-90	70-93
Explosion °C.....	ca. 600		ca. 560	ca. 550	520-630	490-520	510-530	500-510	480-510
Distillate (ash H <sub>2</sub> O free) vol. %									
Light oil, 0-170°.....	0.0	1-12	2.5-23	0-12	1.0-6.6	1.5-6.7	1-9	3-8	2.5-10
Medium oil, 170-230°.....	1-17	6-23	11-16	0-59	10-14	14.7-18	16-24	13-17	21-24
Heavy oil, 230-270°.....	6-14	11-24	11-19	1-36	8.5-13	4.9-14	8.8-18	11-13	9-12
Anthracene oil, 270-350°.....	19-27	19-51	18-31	9-66	9.9-22	12.9-21	19-24.5	19-21	17-24
Pitch (residue) %.....	50-65	18-51	31-37	1-34	52-66	47.6-55	31-47	44-51	39-41
Coke in pitch %.....	16-34	25-39	33		32-47	32-40	16-27	20-25	21-22
C %.....	89.6-92.2	89.3-93.0	91.4-92.2	87.4-91.4	90.4-93	89.3-90.4	87.6-89.9	87.9-88.8	87.1-89.3
H %.....	5.1-5.7	5.5-9.2	6.3-7.2	6.0-7.8	4.7-5.5	5.9-6.4	6.0-7.3	6.6-7.2	6.7-7.1
O + N %.....	2.2-4.0	0.4-1.7	0.5-1.1	1.4-4.9	1.7-3.2	3.2-3.9	2.6-4.9	4.1-4.7	3.6-5.2
S %.....	0.4-1.2	0.6-1.0	0.4-0.9	0.4-0.9	0.5-1.0	0.4-0.7	0.4-0.6	0.5-0.9	0.3-0.6
H per 1000 C.....	52-59	58-101	66-77	62-83	1.8-57	60-66	61-77	68-75	69-74
Comp. of Tar { Water %.....	0.6-6.7	0.0-36	0.3-10	0.0-1.8	0.0-8.7	1-7.3	0.8-3.6	1.1-2.8	1.3-5.8
Ash %.....	0.04-0.36	0.0-0.67	0.0-0.2	0.0-0.04	0.0-0.06	0.01-0.07	0.00-0.09	0.00-0.03	0.0
Combustible %.....	93-99	63.1-100	89-99	98-100	91-100	92-98	96-99	97-99	94-98
Heat of Combustion kg-cal/kg									
Net { Experimental.....	8.27-8.85	ca. 5.65-9.57	8.18-9.31	8.84-9.12	8.06-8.74	8.15-8.71	8.62-8.82	8.59-8.76	8.28-8.76
Water-free oil (calc.).....	8.77-8.92	8.99-9.59	9.09-9.34	8.86-9.14	8.75-8.83	8.77-8.86	8.83-9.08	8.84-8.90	8.79-8.90
Gross.....	9.09-9.22	9.39-10.1	9.53-9.73	9.25-9.51	9.01-9.16	9.10-9.21	9.17-9.48	9.22-9.30	9.20-9.27
Coke.....	7.6-17	3.1-11	7.5-11	0.4-3.6	15-33	15-22	4-11	7-10	7.1-7.3
Free Carbon.....	2.2-10	0.0-4	0.0-4	0.0-0.2	9-28	10-19	1-6	3-6	2.3-3.0
Naphthalene.....	0.5-10	0.3-10	0.0-3	0.8-10.5	4-6	1-3	0.2-2.5	0.1-1.0	0.6-2.1
Engler viscosity { 20°C.....		1.8-4.4		1.4-2	43-150	23-115	2.5-52	32-40	8-13
35°C.....	15-103				9-91	7-35	4-12	7-10	3-5
50°C.....	4.9-38				4-25	3-8.6	1.5-4	2.7-3.4	2.0-2.5
75°C.....	2.5-4.8								
100°C.....	1.4-1.7	1-1.2		0.95-1.07	1.5-2.4	1.5-2.2	1.0-1.4	1.2-1.4	1.18-1.22

## Diesel Motor Oils (223)

Type of oil	$d_{15}^{15}$	Engler $\eta$ , 80°	Flash °C	Fire °C	%H	%C
Lignite { Crude lignite oil... .	0.9	1.02			12.4	85.6
Paraffin oil.....	.916	1.09	98	112	11.5	85.9
Soft paraffin.....	.894	1.01	123	142	11.8	85.7
Petroleum gas oil.....	.855	1.13	74	107	13.6	83.7
Rumanian crude oil.....	.858	1.12	10	10	12.3	83.1

## Diesel Motor Oils (223).—(Continued)

Type of oil	$d_{15}^{15}$	Engler $\eta$ , 80°	Flash °C	Fire °C	%H	%C
Rumanian gas oil.....	0.853	1.08	66	101	12.2	85.0
Solar oil.....	.849	1.03	81	106	13.3	85.7
Tegernsee crude.....	.868	1.01	56	81	11.1	86.9
Texas gas oil.....	.892	0.98	114	128	12.2	86.4
Refined petroleum.....	.879	1.03	57	72	14.2	85.1

## Gasworks and Coke Oven Tar Distillates and "Diesel Engine Tar Oils" (150)

Property	Coal tar distillates			Petroleum oils		
	Average	Maximum	Minimum	Average	Maximum	Minimum
Sp. gr.....	1.02	1.09	0.95	0.91	0.96	0.86
Water %.....	1.1	12	0	0.91	9.5	0
Carbon %.....	89.2	90.0	87.1	85.4	88.3	83.4
Hydrogen %.....	7.3	8.0	6.5	11.5	12.5	10.9
O + N %.....	3.9	4.8	3.0	1.3	2.2	0.07
Sulphur %.....	0.64	1.0	0.3	1.3	2.8	0.04
Ash %.....	0.005	0.10	0	0.05	0.39	0
Closed flash point °F.	164	208	97	187	280	<60
Viscosity Redwood						
70°F.....	9	23	7	780	4800	9
Gross BTU × 10 <sup>-3</sup> ...	17.4	17.9	16.4	19.0	19.7	17.6
Net BTU × 10 <sup>-3</sup> ...	16.6	17.2	15.9	17.8	18.5	16.5
Engler distillation %						
at 250°C.....	58	76	28	5	13	1
Engler distillation %						
at 300°C.....	80	94	51	19	24	13
Retort test % at						
350°C.....				28.5	30	14
Coke yield %.....	3	15	1	3	12	0.2
Free carbon %.....	0.26	5.2	0			
Tar acids %.....	9.5	30	Tr.			
Asphaltum %.....				12.0	37	1.5
Spontaneous ignition						
°C.....	480	520	415	264	264	254

## TERMINOLOGY AND SPECIFICATIONS FOR PETROLEUM PRODUCTS OF COMMERCE

The characteristics that should be possessed by a "good" petroleum product for use under a given set of conditions may be inferred from the specifications established by law, custom, or fiat for such products. Specifications of this character for different countries can be found in the following publications:

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## FLASH POINTS OF SATURATED VAPORS OF COMBUSTIBLE LIQUIDS

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**1. Pure Substances.**—The flash point of the vapor above a liquid is the temperature at which ignition will occur. The observed value is materially dependent upon the type of apparatus used (*v. p.* 150 for comparison of values with different types of apparatus). The lower limit of the flash point of a pure liquid is approximately the temperature at which its vapor pressure is equal to  $B/kN$  where  $B$  is the barometric pressure,  $N$  is the number of moles of  $O_2$  required for complete combustion of one mole of the liquid, and  $k$  is a constant varying with the type of apparatus employed *cf.* (4). The flash point varies with the barometric pressure at the same rate as the boiling point.

In the accompanying table are shown for a number of liquids; (a) the value of  $N$ , (b) the observed flash point as recorded in the literature and (c) the flash point as calculated from the above relation, assuming  $k = 8$ . A better agreement between observed and calculated flash point might perhaps be obtained by using different values of  $k$  for different types of apparatus but the recorded flash points vary greatly and a careful and comprehensive investigation is needed.

Formula	Name	N	Flash point		Lit.
			Observed	Calculated, min.	
CS <sub>2</sub>	Carbon disulfide.....	3	-25.5 to -20	-27	(4)

## HYDROCARBONS

C <sub>6</sub> H <sub>6</sub>	Benzene.....	7.5	-12 to 10	-13	(4, 5)
C <sub>6</sub> H <sub>12</sub>	Cyclohexane.....	9	-17	-17	
C <sub>6</sub> H <sub>14</sub>	Hexane.....	9.5	-18	-26	(4)
C <sub>7</sub> H <sub>8</sub>	Toluene.....	9	6.5 to 30	6.5	(4, 5)
C <sub>7</sub> H <sub>16</sub>	Heptane.....	11	-1 to 17	-5	(5)
C <sub>8</sub> H <sub>10</sub>	Ethylbenzene.....	10.5	15.5	23	(4)
C <sub>8</sub> H <sub>10</sub>	Xylene.....	10.5	29 to 50	25	(5)
C <sub>8</sub> H <sub>18</sub>	Octane.....	12.5	17	15	(4)
C <sub>9</sub> H <sub>12</sub>	n-Propylbenzene....	12	30.5	40.5	(4)
C <sub>10</sub> H <sub>8</sub>	Naphthalene.....		86		(4, 5)
C <sub>10</sub> H <sub>12</sub>	Tetralin.....		78		(3)
C <sub>10</sub> H <sub>14</sub>	sec-Butylbenzene....		52		(4)
C <sub>10</sub> H <sub>16</sub>	Dekalin.....		58		(3)

Formula	Name	N	Flash point		Lit.
			Observed	Calculated, min.	
HALIDES					
C <sub>2</sub> H <sub>4</sub> Cl <sub>2</sub>	Dichloroethylene.....		17		(8)
C <sub>6</sub> H <sub>4</sub> Cl <sub>2</sub>	<i>o</i> -Dichlorobenzene....		77		(8)
C <sub>6</sub> H <sub>4</sub> Cl <sub>2</sub>	<i>p</i> -Dichlorobenzene....	9.5	67 to 78	55	(5, 8)
C <sub>6</sub> H <sub>5</sub> Br	Bromobenzene.....	8.5	65	42	(8)
C <sub>6</sub> H <sub>5</sub> Cl	Chlorobenzene.....	8.5	27.5 to 39	23.5	(5, 8)

## ALCOHOLS and PHENOLS

CH <sub>3</sub> O	Methyl alcohol.....	1.5	-1 to 32	13	(4, 5)
C <sub>2</sub> H <sub>5</sub> O	Ethyl alcohol.....	3	9.0 to 32.0	14	(4, 5)
C <sub>3</sub> H <sub>7</sub> O	n-Propyl alcohol.....	4.5	22.5 to 45.5	25	(4, 5)
C <sub>3</sub> H <sub>7</sub> O	Isopropyl alcohol.....		11.75 to 14.5		(4)
C <sub>4</sub> H <sub>9</sub> O	n-Butyl alcohol.....		35 to 35.5		(4)
C <sub>4</sub> H <sub>9</sub> O	Isobutyl alcohol.....	6	27.5	28	(4)
C <sub>5</sub> H <sub>11</sub> O	Isoamyl alcohol.....	7.5	40 to 42	44	(4)
C <sub>6</sub> H <sub>5</sub> O	Phenol.....		79		(4)
C <sub>6</sub> H <sub>5</sub> O <sub>2</sub>	Catechol.....		127		(4)
C <sub>6</sub> H <sub>5</sub> O <sub>2</sub>	Resorcinol.....	6.5	152	160	(4)
C <sub>6</sub> H <sub>5</sub> O <sub>2</sub>	Hydroquinol.....	6.5	165	167.5	(4)
C <sub>6</sub> H <sub>7</sub> O	Cyclohexanol (hexalin).....		68		(3)
C <sub>7</sub> H <sub>9</sub> O	o-Cresol.....	8.5	81 to 83	79	(4, 5)
C <sub>7</sub> H <sub>9</sub> O	m-Cresol.....	8.5	86	89.5	(4)
C <sub>7</sub> H <sub>9</sub> O	p-Cresol.....	8.5	86	90.5	(4)
C <sub>10</sub> H <sub>8</sub> O	β-Naphthol.....	11.5	161	139	(5)

## ALDEHYDES, KETONES AND ETHERS

C <sub>2</sub> H <sub>5</sub> O	Methyl ether.....		-41		(5)
C <sub>3</sub> H <sub>6</sub> O	Acetone.....	4	-18 to 2	-19	(2, 5)
C <sub>4</sub> H <sub>10</sub> O	Ethyl ether.....	6	-41 to -20	-43	(5)
C <sub>7</sub> H <sub>6</sub> O	Benzaldehyde.....	8	62.5	63	(5)

## ACIDS

C <sub>7</sub> H <sub>6</sub> O <sub>2</sub>	Benzoic acid.....	7.5	121 to 131	136	(4, 5)
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## ESTERS

C <sub>3</sub> H <sub>6</sub> O <sub>2</sub>	Ethyl formate.....	3.5	-19.5	-18	(4)
C <sub>3</sub> H <sub>6</sub> O <sub>2</sub>	Methyl acetate.....	3.5	-15.5 to 4.6	-15	(4)
C <sub>4</sub> H <sub>7</sub> ClO <sub>2</sub>	Chloroethyl acetate		67		(8)

## ESTERS.—(Continued)

Formula	Name	N	Flash point		Lit.
			Observed	Calculated, min.	
C <sub>4</sub> H <sub>7</sub> ClO <sub>2</sub>	Ethyl chloroacetate...		54		( <sup>8</sup> )
C <sub>4</sub> H <sub>8</sub> O <sub>2</sub>	Ethyl acetate.....	5	-5.0 to 5	-5	( <sup>4</sup> )
C <sub>4</sub> H <sub>8</sub> O <sub>2</sub>	Methyl propionate...	5	-2.0	-3	( <sup>4</sup> )
C <sub>4</sub> H <sub>8</sub> O <sub>2</sub>	<i>n</i> -Propyl formate....	5	-3.0	-2	( <sup>4</sup> )
C <sub>4</sub> H <sub>8</sub> O <sub>2</sub>	Isopropyl formate....		-5.5		( <sup>4</sup> )
C <sub>5</sub> H <sub>10</sub> O <sub>2</sub>	<i>n</i> -Butyl formate.....		17.5		( <sup>4</sup> )
C <sub>5</sub> H <sub>10</sub> O <sub>2</sub>	Ethyl propionate....	6.5	12.5	9	( <sup>4</sup> )
C <sub>5</sub> H <sub>10</sub> O <sub>2</sub>	Methyl <i>n</i> -butyrate...	6.5	14	11	( <sup>4</sup> )
C <sub>5</sub> H <sub>10</sub> O <sub>2</sub>	<i>n</i> -Propyl acetate....	6.5	14.5	10.5	( <sup>4</sup> )
C <sub>5</sub> H <sub>10</sub> O <sub>2</sub>	Isopropyl acetate....		4.5		( <sup>4</sup> )

## NITROGEN COMPOUNDS

C <sub>6</sub> H <sub>3</sub> ClN <sub>2</sub> O <sub>4</sub>	Dinitrochlorobenzene.		187		( <sup>5</sup> )
C <sub>6</sub> H <sub>4</sub> ClNO <sub>2</sub>	Nitrochlorobenzene...		127		( <sup>5</sup> )
C <sub>6</sub> H <sub>4</sub> N <sub>2</sub> O <sub>4</sub>	<i>m</i> -Dinitrobenzene....		150		( <sup>5</sup> )

## NITROGEN COMPOUNDS.—(Continued)

Formula	Name	N	Flash point		Lit.
			Observed	Calculated, min.	
C <sub>6</sub> H <sub>5</sub> NO <sub>2</sub>	Nitrobenzene.....	7.5	88 to 90	89.5	( <sup>4</sup> , <sup>5</sup> )
C <sub>6</sub> H <sub>7</sub> N	Aniline.....	9	71	70	( <sup>5</sup> )
C <sub>8</sub> H <sub>11</sub> N	Dimethylaniline.....	12	61 to 76	70	( <sup>5</sup> )
C <sub>10</sub> H <sub>9</sub> N	$\alpha$ -Naphthylamine....	13.5	157	144	( <sup>5</sup> )

2. Mixtures.—See p. 150.

## LITERATURE

(For a key to the periodicals see end of volume)

- (<sup>1</sup>) Battle, *Handbook of Industrial Oil Engineering*, p. 262; Philadelphia, Lipincott, 1920. (<sup>2</sup>) Coste, 173, 42: 168; 17. (<sup>3</sup>) Gardner, *Paint Mfgs. Assoc. U. S., Circular* 248: 62; 25. (<sup>4</sup>) Mack, Boord and Barham, 45, 15. [963; 23. (<sup>5</sup>) Ormondy and Craven, *Chem. Trade J.*, 70: 41; 22. (<sup>6</sup>) Schrauth, 416, 2: 184; 21. (<sup>7</sup>) Sherman, Gray and Hammerschlag, 45, 1: 13; 09. (<sup>8</sup>) Weber and Wynne, 78, 46: 197; 24.

## QUANTITATIVE EFFECTS OF SOME COMPOUNDS UPON DETONATION IN INTERNAL COMBUSTION ENGINES

T. A. BOYD

The detonation or "knock" that characterizes combustion in gasoline engines under certain conditions is influenced primarily by the chemical composition or structure of the fuel, and secondarily by the compression to which the combustion mixture is subjected, by its temperature, and by the point in the cycle at which ignition occurs, as well as by some more minor factors, such as the shape of the combustion chamber and the location of the spark plug (<sup>1</sup>, <sup>8</sup>). The principal types of compounds that may be used as fuels in the gasoline engine arrange themselves in the order of decreasing tendency to knock as follows (<sup>2</sup>, <sup>8</sup>): ethers, paraffins, olefins, naphthenes, aromatics, alcohols. The tendency of any given fuel to detonate may either be increased or decreased as desired by the addition of a suitable compound to the combustion mixture, the amount required being very small in some cases.

Die Detonation oder das Klopfen (knock), welche die Verbrennung in Benzinmotoren unter gewissen Bedingungen kennzeichnet, ist zunächst von der chemischen Zusammensetzung oder Struktur des Brennstoffes beeinflusst, in zweiter Linie von der Kompression, dem das Verbrennungsgemisch ausgesetzt ist, von seiner Temperatur und von der Lage des Zündpunktes im Kreisprozess. In gleicher Weise hängt es noch von kleineren Faktoren ab, wie der Form des Verbrennungsraumes und der Lage der Zündkerze (<sup>1</sup>, <sup>8</sup>). Die hauptsächlichsten Arten die als Motorbetriebsstoffe in Frage kommen, ordnen sich selbst in abnehmender Ordnung ihrer Fähigkeit zu klopfen, in folgender Weise (<sup>2</sup>, <sup>8</sup>): Äther-Arten, Paraffine, Olefine, Naphtene, Stoffe der aromatischen Reihe und Alkohole. Die Neigung irgend eines gegebenen Betriebsstoffes zu detonieren, kann nach Bedarf erhöht oder erniedrigt werden, durch Hinzufügung einer passenden Verbindung zum Betriebsstoff. Die dazu notwendige Menge ist in manchen Fällen sehr gering.

La détonation ou le "cognage" qui caractérise la combustion dans les moteurs à benzine sous certaines conditions, est influencée premièrement par la composition chimique ou la structure du carburant et secondairement par la compression à laquelle le mélange combustible est soumis, par sa température, et par le point du cycle auquel l'allumage se produit, de même que par quelques autres facteurs de moindre importance, tels que la forme de la chambre de combustion et la situation de la bougie d'allumage (<sup>1</sup>, <sup>8</sup>). Les principaux types de composés qui peuvent être utilisés comme carburants dans les moteurs à essence peuvent être classés dans l'ordre de leur tendance décroissante à détoner, comme suit (<sup>2</sup>, <sup>8</sup>): Ethers, Paraffines, Oléfines, Naphthènes, Aromatiques et Alcools. La tendance de chaque carburant à détoner peut être augmentée ou diminuée suivant le désir, par l'addition d'un composé convenable au mélange de combustion, la quantité requise pour produire l'effet étant dans certains cas très faible.

La detonazione (Knock) che, in certe condizioni, caratterizza la combustione nei motori a essenza, è influenzata anzitutto dalla composizione chimica o struttura del carburante, e in secondo luogo dal grado di compressione della miscela, dalla sua temperatura, e dal momento in cui l'accensione avviene durante il ciclo. Essa dipende pure da altri fattori secondari, come la forma della camera di combustione e la posizione della candela (<sup>1</sup>, <sup>8</sup>). I principali tipi di composti che possono adoperarsi come carburanti nei motori a essenza si possono disporre nell'ordine seguente graduandoli secondo la tendenza decrescente a detonare (<sup>2</sup>, <sup>8</sup>): eteri, paraffine, olefine, nafteni, sostanze aromatiche, alcoli. La tendenza di un dato combustibile a detonare può essere accresciuta o diminuita a piacere aggiungendo alla miscela combustibile un adatto composto. La quantità di sostanza a ciò necessaria è in alcuni casi molto piccola.



# RELATIVE EFFECTS OF SOME MISCELLANEOUS COMPOUNDS FOR SUPPRESSING DETONATION IN ENGINES

Aniline in concentration of 2% of the fuel by volume taken as standard of effect. All measurements made with bouncing-pin apparatus, using kerosene as fuel (1, 3, 4). The values given below are, respectively, (a) amount in grams required to give an "anti-knock" effect equivalent to 1 g of aniline, and (b) reciprocal of the number of mols required to give an "anti-knock" effect equivalent to 1 mol of aniline.

Compound	Formula	(a) Wt. for given effect	(b) Rel. mol. effectiveness	Lit.
Aniline.....	$C_6H_5NH_2$	1	1	
Benzene.....	$C_6H_6$	9.8	0.085	(1)
Toluene.....	$C_6H_5CH_3$	8.8	0.112	(1)
Xylene.....	$C_6H_4(CH_3)_2$	8.0	0.142	(1)
Alcohol.....	$C_2H_5OH$	4.75	0.104	(5)
Ethyl iodide.....	$C_2H_5I$	1.55	1.09	(6)
Diethyl selenide.....	$(C_2H_5)_2Se$	0.214	6.9	(6)
Diphenyl selenide.....	$(C_6H_5)_2Se$	0.49	5.2	(6)
Diethyl telluride.....	$(C_2H_5)_2Te$	0.075	26.6	(6)
Diphenyl telluride.....	$(C_6H_5)_2Te$	0.139	22.0	(6)
Triphenylphosphine.....	$(C_6H_5)_3P$	3.08	0.91	(7)
Triphenylarsine.....	$(C_6H_5)_3As$	2.44	1.35	(7)
Triphenylstibine.....	$(C_6H_5)_3Sb$	1.56	2.42	(7)
Tetraethyl tin.....	$(C_2H_5)_4Sn$	0.66*	3.8*	(7)
Tetraethyl lead.....	$(C_2H_5)_4Pb$	0.0295	118	(3)
Tetraphenyl lead.....	$(C_6H_5)_4Pb$	0.080†	69.5†	(9)
Diphenyl diethyl lead...	$(C_6H_5)_2Pb$	0.041†	110†	(9)
Triethylbismuthine.....	$(C_2H_5)_3Bi$	0.135†	23.8†	(9)
Triphenylbismuthine...	$(C_6H_5)_3Bi$	0.22†	21.5†	(9)
Nickel carbonyl.....	$Ni(CO)_4$	0.053†	35†	(9)
Dimethyl cadmium.....	$(CH_3)_2Cd$	1.23†	1.25†	(9)
Titanium tetrachloride..	$TiCl_4$	0.64†	3.2†	(9)

\* Values for tetraethyl tin in doubt because of preignition induced by the compound.

† These figures computed from the data of the original article, and converted to the aniline scale used for the other values in the table, on which tetraethyl lead is 118, instead of 100 as it is in the system of comparison used by the authors.

## RELATIVE EFFECTS OF SOME COMPOUNDS OF NITROGEN FOR SUPPRESSING DETONATION IN ENGINES

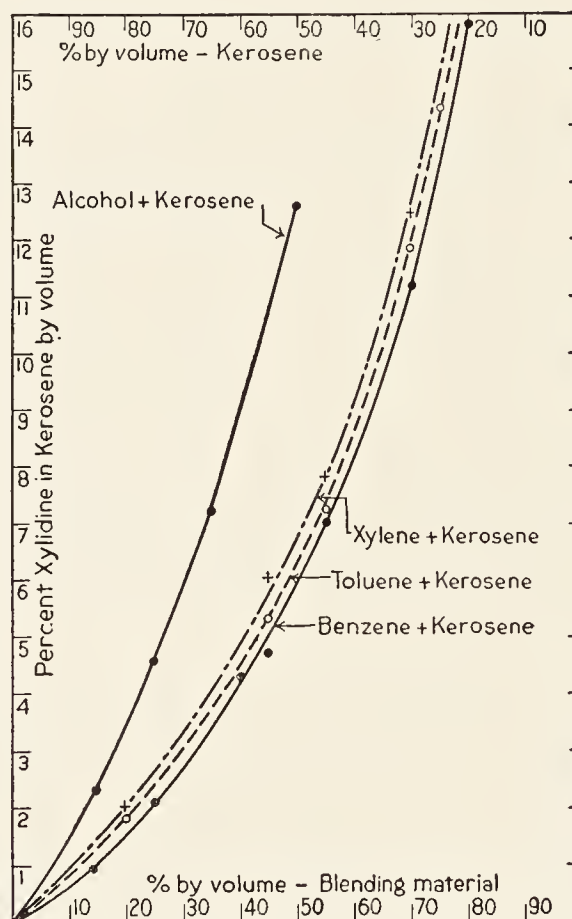
Aniline in concentrations up to 3% of the fuel by volume taken as standard of effect. All measurements made with bouncing-pin apparatus, using kerosene as fuel (4). The values given below are, respectively, (a) amount in grams required to give an "anti-knock" effect equivalent to 1 g of aniline, and (b) reciprocal of the number of mols required to give an "anti-knock" effect equivalent to 1 mol of aniline. Negative values are marked (-).

Compound	Formula	(a) Wt. for given effect	(b) Rel. mol. effectiveness
Aniline.....	$C_6H_5NH_2$	1	1
Cumidine.....	$(CH_3)_3C_6H_2NH_2$	0.96	1.51
Diphenylamine.....	$(C_6H_5)_2NH$	1.21	1.5
m-Xylidine.....	$(CH_3)_2C_6H_3NH_2$	0.92	1.4
Monomethylaniline...	$C_6H_5NHCH_3$	0.83	1.4
Toluidine.....	$CH_3C_6H_4NH_2$	0.94*	1.22*
Amylamino benzene...	$C_5H_{11}C_6H_4NH_2$	1.53	1.15
Ethylamino benzene..	$C_2H_5C_6H_4NH_2$	1.14	1.14
Aminodiphenyl.....	$C_6H_5C_6H_4NH_2$	1.6	1.14

Compound	Formula	(a) Wt. for given effect	(b) Rel. mol. effectiveness
Methyl-o-toluidine(7).	$CH_3C_6H_4NHCH_3$	1.15	1.13
n-Butylaminobenzene	$C_4H_9C_6H_4NH_2$	1.44	1.11
n-Propylaminobenzene	$C_3H_7C_6H_4NH_2$	1.32	1.10
Monooctylaniline....	$C_8H_{17}NHC_2H_5$	1.27	1.02
Mono-n-propylaniline	$C_6H_5NHC_3H_7$	1.95	0.75
Ethyldiphenylamine..	$C_2H_5N(C_6H_5)_2$	3.65	0.58
Mono-n-butylaniline..	$C_6H_5NHC_4H_9$	3.1	0.52
Diethylamine.....	$(C_2H_5)_2NH$	1.59	0.495
Di-n-propylaniline...	$C_6H_5N(C_3H_7)_2$	7.15	0.27
Mono-isoamylaniline.	$C_6H_5NHC_6H_{11}$	7.1	0.248
Diethylaniline.....	$C_6H_5N(C_2H_5)_2$	6.7	0.24
Dimethylaniline.....	$C_6H_5N(CH_3)_2$	6.2	0.21
Ethylamine.....	$C_2H_5NH_2$	2.4	0.20
Triethylamine.....	$(C_2H_5)_3N$	7.95	0.14
Triphenylamine.....	$(C_6H_5)_3N$	30.0	0.09
Ammonia.....	$NH_3$	2.0(-)	0.09(-)
Isopropyl nitrite....	$C_3H_7NO_2$	0.085(-)†	11.5(-)†

\* Average of o-, m-, and p-values.

† Approx. only. Organic nitrates and nitrites in general are inducers of detonation, the former being more effective than the latter, and the alkyl compounds much more effective than the aryl. Chlorine and bromine, as well as some of their compounds, induce detonation also.



Relative effect of hydrocarbons for suppressing detonations in engines (1, 5). Kerosene as fuel; xylidine as standard of effect upon detonation.

## LITERATURE

(For a key to the periodicals see end of volume)

- (1) Midgley and Boyd, 45, 14: 589; 22. (2) Midgley, 244, 7: 495; 20. (3) Midgley and Boyd, 45, 14: 894; 22. (4) Boyd, 45, 16: 893; 24. (5) Midgley and Boyd, 244, 10: 451; 22. (6) Midgley, 45, 15: 421; 23. (7) Boyd, O. (8) Ricardo, 381, 11: 92; 21. (9) Charch, Mack and Boord, 45, 18: 334; 26.

## LUBRICANTS AND LUBRICATION

J. H. HYDE

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For density, viscosity and other physical properties of lubricants, see p. 136.

## JOURNAL BEARING FRICTION

In the following tables the value of the coefficient of friction of a journal bearing is given for different values of the quantity:

$$\frac{60\eta N}{P} = 60 \times \frac{\text{Absolute viscosity of lubricant at bearing temperature} \times \text{r. p. s.}}{\text{Pressure on bearing}}, \text{ where pressure on bearing} =$$

$$\frac{\text{Total load on bearing}}{\text{Length of bearing} \times \text{diameter of journal}}$$

COEFFICIENT OF KINETIC FRICTION FOR DIFFERENT VALUES OF THE RATIO  $\frac{\text{CLEARANCE}}{\text{DIAMETER}}$  (4)

$\frac{60\eta N}{P}$	Lasche		Sommerfeld calc.		Lasche		Sommerfeld calc.		Lasche		Sommerfeld calc.		Lasche		Sommerfeld calc.	
	1/1000		1/500		1/250		1/100									
100	0.005	0.006	0.0045	0.0025	0.0035	0.0032	0.003	0.010								
250	0.0115	0.012	0.011	0.006	0.0095	0.0035	0.0075	0.010								
500	0.018	0.024	0.017	0.012	0.016	0.0060	0.0115	0.0096								
750	0.024	0.036	0.021	0.018	0.019	0.0090	0.0135	0.0092								
1000	0.030	0.048	0.025	0.024	0.020	0.0125	0.0150	0.0090								
1250	0.036	0.060	0.029	0.030	0.021	0.0158	0.0165	0.0090								

COEFFICIENT OF KINETIC FRICTION (4)

$\frac{60\eta N}{P}$	100	200	300	400	500	600	700	800	900	1000	1100	1200
Stribeck white metal bearing 5.40 in. long. . . .	0.0128	0.0190	0.0245	0.0290	0.0335	0.0370	0.0405	0.0435	0.0462	0.0482	0.0500	0.0512
Bronze bearing 9.06 in. long. . . . .	0.0085	0.0125	0.0156	0.0182	0.0205	0.0222	0.0240	0.0255	0.0270	0.0282	0.0295	0.0305
Hersey full bearing. Clearance Diameter = 0.04. . . . .	0.0038	0.0055	0.0075	0.0092	0.0110	0.0130	0.0145	0.0165	0.0182	0.0200	0.0220	0.0238



## RUPTURE OF LUBRICATING FILM

Values of  $\frac{60\eta N}{P}$  for rupture of lubricating film in a journal bearing, for bearings of different clearances (4).

$\frac{60\eta N}{P}$	60	50	40	35	30	25	20	15	12	11
Diameter										
Clearance at rupture . . .	260	300	350	400	460	555	700	900	1200	1400

## EFFECT OF VARIOUS LUBRICANTS ON STATIC FRICTION

Coefficient of static friction between surfaces of mild steel and various metals when lubricated with various oils, for pressures ranging from 10 to 120 lb./in.<sup>2</sup> and at a temperature of 16°C; "Deeley" Machine Tests (3).

Lubricant	Coefficient of static friction							
	Mild steel against							Hardened steel against Bronze*
	White metal	Axle steel	Cast iron	Wrought iron	Gun metal	"Stones" bronze	Aluminum	
Rape.....	0.109	0.137	0.102	0.136	0.155	0.124	0.111	0.080
Lard.....	0.118	0.110	0.133	0.125	0.155	0.117	0.100	0.082
Castor.....	0.138	0.121	0.131	0.136	0.166	0.121	0.126	0.109
FFF cylinder.....	0.165	0.147	0.179	0.159	0.177	0.128	0.137	0.120
Bayonne.....	0.185	0.157	0.214	0.185	0.207	0.158	0.145	0.132
Mobiloil BB.....	0.188	0.174	0.182	0.174	0.233	0.152	0.145	
Sperm.....	0.195	0.121	0.138	0.146	0.214	0.173	0.156	0.111
Mobil E.....								0.115
Victory red.....								0.117

\* Average between 10 and 120 lb./in.<sup>2</sup>

## COEFFICIENT OF KINETIC FRICTION FOR SURFACES OF CAST IRON AND STEEL WHEN LUBRICATED WITH VARIOUS OILS

Pressure 30 lb./in.<sup>2</sup>; 22° to 24°C. Variation of coefficient of kinetic friction with rubbing speed and quantity of stearic acid addition to lubricant. "Deeley" Type Machine (4).

Rubbing speed, ft. per min	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
Mineral auto oil alone.....	0.26	0.23	0.21	0.19	0.17	0.155	0.14	0.12	0.115	0.11	0.105	0.105
+½ % stearic acid.....	0.105	0.090	0.080	0.075	0.070	0.065	0.060					
+2 % stearic acid.....	0.085	0.075	0.065	0.060	0.055	0.053	0.052	0.050	0.048	0.047	0.046	0.045

## EFFECT OF ADDITIONS TO BAYONNE OIL

Effect of additions of rape oil and of fatty acids to Bayonne oil (straight mineral). Coefficient of static friction between surfaces of hardened steel and bronze. "Deeley" Machine Tests. Pressure 10 to 120 lb./in.<sup>2</sup> 16°C (2).

	For a neutral rape oil. No <i>free</i> fatty acid						For a rape oil containing 2.44% <i>free</i> fatty acid						
Per cent of added oil .....	0	4	8.2	20.5	41.0	100	0	2	4	8.2	20.5	40.9	100
Coeff. of static friction.....	0.132	0.110	0.105	0.099	0.096	0.083	0.132	0.199	0.102	0.099	0.093	0.088	0.080

	For additions of oleic acid									
Per cent oleic acid added...	0	0.20	0.40	0.80	1.50	2	10	40	80	100
Coeff. of static friction.....	0.132	0.102	0.097	0.092	0.088	0.087	0.086	0.085	0.079	0.075

## EFFECT OF PRESSURE ON COEFFICIENT OF STATIC FRICTION (5)

Pressure between surfaces, lb./in. <sup>2</sup>	8.6	17.3	26.0	36.6	43.3	52.0
Mild steel and cast iron with rape oil.....	0.205	0.200	0.203	0.208	0.218	0.229
Mild steel and gun metal with FFF cylinder oil.....	0.172	0.100	0.081	0.067	0.058	0.052
Mild steel and gun metal with sperm oil.....	0.020	0.029	0.036	0.045	0.053	0.061

VARIATION OF STATIC FRICTION WITH LUBRICANT FOR VARIOUS LUBRICANTS UNDER CONSTANT PRESSURE OF 10 LB./IN.<sup>2</sup> (5)

Mild steel against	Clock oil (HB)	Bayonne	Type-writer	Victory red	FFF cylinder	Manchester spindle	Castor	Sperm	Trotter (hard)	Olive	Rape	Valvoline cylinder
Cast iron.....	0.271	0.213	0.211	0.195	0.193	0.183	0.153	0.127	0.123	0.119	0.119	0.143
Gun metal.....	0.275	0.234	0.294	0.246	0.236	0.262	0.169	0.189	0.152	0.196	0.136	

## LUBRICATING VALUE OF OILS UNDER CONDITIONS OF HEAVY LOADS AND TEMPERATURES UP TO 100°

Tests made on the Daimler-Lanchester Worm Gear Testing Machine at the National Physical Laboratory, England, show that the value of a straight mineral oil as a lubricant, when the load is great, diminishes rapidly above a certain critical temperature. It has been found by a very large number of tests under the same

conditions of speed, load and supply of lubricant at a given temperature, that the efficiency of the worm gear in the testing machine remains remarkably constant at the load selected for the tests, and, as differences of efficiency could be determined to 0.1 % (absolute efficiency to 0.2 %), the efficiency-temperature values obtained give a valuable indication of the quality of the lubricant.

EFFECT OF TEMPERATURE ON GEAR EFFICIENCY

Variation of efficiency of power transmission by worm gear, with temperature of lubricant, for a straight mineral oil (Bayonne oil). This example is typical of all mineral oils (5).

°C	15 to 42	45	50	55	60	65	70
Gear efficiency, %	95.0	94.7	94.2	93.8	93.4	93.1	92.9

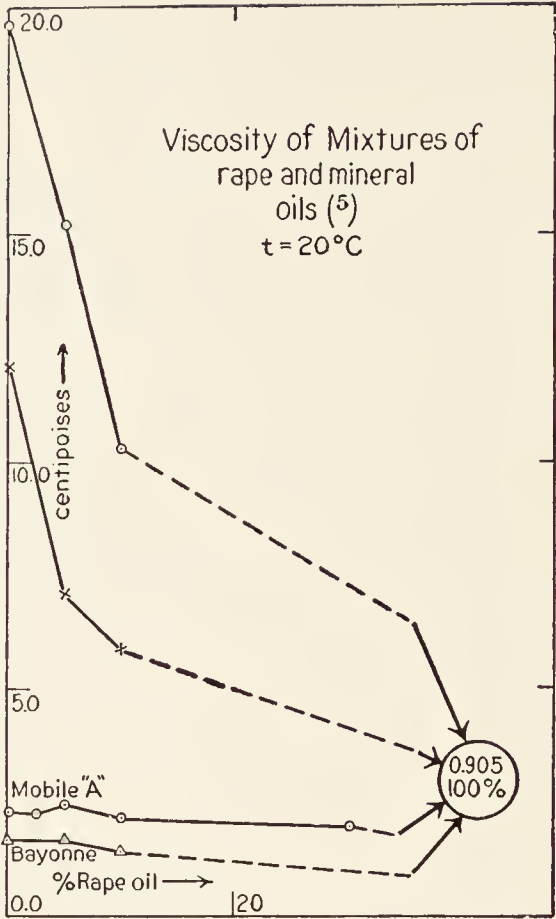
°C	75	80	85	90	95	100
Gear efficiency, %	92.8	92.7	92.6	92.5	92.5	92.4

The following critical temperatures were observed: Bayonne, 42°; FFF cylinder, 71°; Victory red oil, 50°; Mobiloil "A," 56°; Mobiloil "BB," 62°; lard, rape, castor and sperm, none observed. A small addition of fatty oil, fatty acid or graphite raises the critical temperature 10 to 20°.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Hersey, 306, 35: 648; 23. (2) Hyde, 115, 111: 708; 21. (3) Hyde, National Physical Laboratory, England, O. (4) Wilson and Barnard, 45, 14: 682; 22. (5) Report of the Lubrications and Lubricants Enquiry Committee, Dept. of Scientific and Industrial Research, England, 1920.



TYPICAL ANALYSES AND PROPERTIES OF GASEOUS FUELS

E. R. WEAVER

The hydrocarbons in natural gases and the hydrogen and saturated hydrocarbons in manufactured gases are usually determined by combustion, and the actual compounds present are not determined. The properties which affect the use of the gas as a fuel (heating value, specific gravity, air required for combustion and products formed by combustion) would be the same for a mixture of the composition stated by the analysis as for the mixture analyzed. For example, a mixture of one volume of

hydrogen and one of ethane has the same values for these properties as two volumes of methane; and in an analysis of manufactured gas they would appear as methane. The "illuminants" of manufactured gas generally include all hydrocarbons present except those of the paraffin series. The first table gives the actual compositions of some typical gases; the second table gives analyses stated in the conventional manner. The same index letter in the two tables refers to the same gas.

ACTUAL COMPOSITION

The last column of each series of hydrocarbons in which a number is entered includes higher homologs

Gas	Constituents of gas, % by volume																	
	H <sub>2</sub>	CO	Saturated hydrocarbons					Illuminants					Inerts					
			CH <sub>4</sub>	C <sub>2</sub> H <sub>6</sub>	C <sub>3</sub> H <sub>8</sub>	C <sub>4</sub> H <sub>10</sub>	C <sub>5</sub> H <sub>12</sub>	C <sub>2</sub> H <sub>4</sub>	C <sub>3</sub> H <sub>6</sub>	C <sub>4</sub> H <sub>8</sub>	C <sub>2</sub> H <sub>2</sub>	C <sub>6</sub> H <sub>6</sub>	C <sub>7</sub> H <sub>8</sub>	CO <sub>2</sub>	O <sub>2</sub>	N <sub>2</sub>		
Natural gases	{	A			90.7	3.8	3.3	0.8	0.4								1.0	
Appalachian field.....		B			84.7	9.4	3.0	1.3									1.6	
		C			80.4	8.7	4.1	4.0	1.3								1.5	
		D			44.7	7.9	21.3	9.9	16.2								1.0	
Oklahoma E.....				74.7	13.0	6.0	1.5	0.8									4.0	
Texas ("wet gas") F.....				50.6	3.1	2.4	8.4							ca. 1 % He			34.5	
Gas "F" after removal of gasolene G.....				54.8	3.3	2.6	0.8							ca. 1 % He			37.5	
Coal gas H.....		52.5	6.8	30.0	0.8	0.12	0.02			2.0	0.3	0.1	0.01	1.1	0.4	1.7	0.6	3.5
Carburetted water gas I.....		32.0	29.8	13.1	2.9	0.3				9.8	2.8	1.7		0.9	0.6	4.8		1.3



## COMPOSITION GIVEN BY CONVENTIONAL METHODS OF ANALYSIS

Gas		Constituents of gas, % by volume									Speci- fic grav- ity (air = 1)	Volume air per volume gas re- quired for com- bustion	Heat of combustion kg-eal per l (1 atm., 15.5°C) to form liquid H <sub>2</sub> O and gaseous CO <sub>2</sub> at 15.5°C	Products of combustion volumes per volume of gas			
		H <sub>2</sub>	CO	CH <sub>4</sub>	C <sub>2</sub> H <sub>6</sub>	C <sub>3</sub> H <sub>8</sub>	Illumi- nants	CO <sub>2</sub>	O <sub>2</sub>	N <sub>2</sub>				CO <sub>2</sub>	H <sub>2</sub> O	N <sub>2</sub>	Total
Natural gases	A.....			84.2	14.8					1.0	0.63	10.5	9.9	1.14	2.13	8.35	11.62
	B.....			79.1	19.3					1.6	0.66	10.8	10.2	1.18	2.16	8.57	11.91
	C.....			63.1	35.4					1.5	0.73	12.0	11.3	1.34	2.32	9.50	13.16
	D.....				38.8	60.2				1.0	1.33	20.9	20.0	2.58	3.57	16.35	22.68
	E.....			62.5	33.5					4.0	0.73	11.6	11.0	1.29	2.26	9.22	12.77
	F.....			23.0	41.5					35.5	0.91	9.2	8.7	1.06	1.70	7.60	10.36
	G.....			50.6	10.9					38.5	0.77	6.7	6.3	0.72	1.36	6.66	8.74
Kern Co., Calif.....				78.6	10.3			9.7		1.4	0.70	9.2	8.7	1.09	1.88	7.33	10.30
Coal gas H.....		51.4	6.8	32.0			3.9	1.7	0.6	3.5	0.41	5.4	5.5	0.55	1.25	4.31	6.11
Carburetted water gas I..		28.5	29.8	19.8			15.8	4.8		1.3	0.71	6.4	6.2	0.99	1.11	5.05	7.15
Coal and coke-oven gases..																	
“700 BTU”.....		44.8	4.3	41.1			6.0	1.1	0.4	2.3	0.42	6.3	6.2	0.61	1.42	4.96	6.99
“600 BTU”.....		48.7	7.8	33.0			4.3	1.5	0.2	4.5	0.41	5.3	5.3	0.53	1.25	4.21	5.99
“550 BTU”.....		49.3	9.4	28.4			3.5	2.3	0.6	6.5	0.43	4.8	4.9	0.49	1.15	3.84	5.48
“500 BTU”.....		51.0	11.0	23.7			3.1	2.6	0.5	8.1	0.44	4.3	4.5	0.45	1.06	3.46	4.97
“450 BTU”.....		41.5	9.6	22.2			3.0	4.2	0.5	19.0	0.54	3.9	4.0	0.44	0.932	3.26	4.63
Carburetted water gas																	
“700 BTU”.....		31.2	28.2	20.2			15.3	2.0		3.1	0.65	6.1	6.2	0.89	1.08	4.82	6.79
“600 BTU”.....		34.8	30.6	15.0			11.5	4.2		3.9	0.65	5.1	5.3	0.80	0.93	4.08	5.81
“500 BTU”.....		40.4	32.7	10.5			8.0	5.1		3.5	0.61	4.1	4.5	0.68	0.81	3.29	4.78
“400 BTU”.....		45.2	36.5	5.2			4.0	6.0		3.1	0.59	3.2	3.6	0.58	0.66	2.55	3.79
“Blue” water gas.....		50.5	40.2	1.2			0.0	4.4		3.8	0.54	2.3	2.7	0.46	0.53	1.85	2.84
Oil gas																	
“800 BTU”.....		38.1	2.8	40.9			12.2			6.0	0.49	7.2	7.1	0.77	1.51	5.74	8.02
“700 BTU”.....		41.5	7.0	36.8			8.4	1.5		4.8	0.47	6.2	6.2	0.67	1.36	4.96	6.99
“600 BTU”.....		45.8	9.6	31.0			4.7	2.8		6.1	0.46	5.3	5.4	0.58	1.21	4.24	6.03
“550 BTU”.....		50.3	10.6	27.4			3.5	2.5		5.7	0.43	4.8	4.9	0.50	1.14	3.84	5.48
“500 BTU”.....		55.2	12.4	23.4			1.6	2.8		4.6	0.40	4.3	4.5	0.45	1.07	3.33	4.85
Producer gas																	
“175 BTU”.....		21.1	19.8	4.0				6.8		48.3	0.80	1.36	1.6	0.31	0.29	1.56	2.16
“150 BTU”.....		15.3	23.2	2.4				6.1		53.0	0.86	1.15	1.3	0.32	0.20	1.44	1.96
“125 BTU”.....		11.6	23.0	1.3				5.5		58.6	0.89	0.95	1.1	0.30	0.14	1.34	1.78
“100 BTU”.....		5.9	23.8	0.4				6.0		63.9	0.95	0.75	0.9	0.30	0.70	1.23	1.60
Blast furnace gas.....		1.2		27.2				8.0		63.6	1.01	0.68	0.8	0.35	0.01	1.18	1.54

## ASPHALTS AND MINERAL WAXES

HERBERT ABRAHAM

Under this heading will be considered the following groups of substances: (1) Mineral waxes; (2) native asphalts; (3) asphaltites; (4) asphaltic pyrobitumens; and (5) pyrogenous asphalts. These five groups are members of the class "Bituminous substances," the first three falling within the group "Bitumens," the fourth within the group "Pyrobitumens," and the fifth within the group "Pyrogenous residues."

## NOMENCLATURE

The definitions which follow show the relationship between these respective groups of substances.

**Bituminous Substances.**—A class of native and pyrogenous substances containing bitumens or pyrobitumens, or resembling them in their physical properties. [This definition includes bitumens, pyrobitumens, pyrogenous distillates (pyrogenous waxes and tars) and pyrogenous residues (pitches and pyrogenous asphalts).]

**Bitumen.**—A generic term applied to native substances of variable color, hardness and volatility; composed of hydrocarbons substantially free from oxygenated bodies; sometimes associated with mineral matter, the non-mineral constituents being *fusible* and largely *soluble* in carbon disulfide; the distillates, fractionated between 300 and 350°C, yield *considerable sulfonation residue*. [This definition includes petroleum, native asphalts, native mineral waxes and asphaltites.]

**Pyrobitumen.**—A generic term applied to native substances of dark color; comparatively hard and non-volatile; composed of hydrocarbons, which may or may not contain oxygenated bodies; sometimes associated with mineral matter, the non-mineral constituents being *infusible*, and relatively *insoluble* in carbon disulfide. [This definition includes the asphaltic and non-asphaltic pyrobitumens and their respective shales.]

**Mineral Wax.**—A term applied to a species of bitumen, also to certain pyrogenous substances; of variable color, viscous to solid consistency; having a *characteristic luster* and *unctuous feel*; comparatively non-volatile; composed of hydrocarbons, substantially free from oxygenated bodies; containing *considerable crystallizable paraffins*; sometimes associated with mineral matter, the non-mineral constituents being easily fusible and soluble in carbon disulfide. [This definition is applied to crude and refined native mineral waxes, also to pyrogenous waxes. Crude native mineral waxes include ozokerite, etc. Refined native mineral waxes include ceresine (refined ozokerite) and montan wax (extracted from lignite or pyropissite by means of solvents). Pyrogenous waxes include the solid paraffins separated from non-asphaltic and mixed-base petroleum, peat, tar, lignite tar and shale tar].

**Asphalt.**—A term applied to a species of bitumen, also to certain pyrogenous substances of *dark color*, variable hardness, comparatively non-volatile; composed of hydrocarbons, substantially free from oxygenated bodies; containing relatively little to no crystallizable paraffins; sometimes associated with mineral matter, the non-mineral constituents being *fusible*, and largely soluble in carbon disulfide; the distillate, fractionated between 300 and 350°C,

yields *considerable sulfonation residue*. [This definition is applied to native asphalts and pyrogenous asphalts. Native asphalts include asphalts occurring naturally in a pure or fairly pure state, also asphalts associated naturally with a substantial proportion of mineral matter, sometimes termed "rock asphalts." The associated mineral matter may be sand, sandstone, limestone, clay, shale, etc. Pyrogenous asphalts include residues obtained from the distillation, blowing, etc., of petroleum (e.g., *residual oil*, produced by the dry distillation of non-asphaltic petroleum, the dry or steam distillation of mixed-base petroleum and the steam distillation of asphaltic petroleum, *blown asphalt*, produced by blowing air through heated residual oils, *residual asphalts*, produced by the steam distillation of mixed-base and asphaltic petroleum, *sludge asphalt*, produced from the acid sludge obtained in the purification of petroleum distillates with sulfuric acid, etc., also from the pyrogenous treatment of wurtzilite (e.g., *wurtzilite asphalt*, produced by depolymerizing wurtzilite in closed retorts).]

**Asphaltite.**—A species of bitumen, including dark colored, comparatively hard and non-volatile solids; composed of hydrocarbons, substantially free from oxygenated bodies and crystallizable paraffins; sometimes associated with mineral matter, the non-mineral constituents being *difficultly fusible* and largely soluble in carbon disulfide; the distillation residue, fractionated between 300 and 350°C, yields *considerable sulfonation residue*. [This definition includes *gilsonite* (conchoidal fracture and characteristic brown streak on porcelain), *glance pitch* (conchoidal to hackly fracture and black streak) and *grahamite* (conchoidal to hackly fracture and black streak).]

**Asphaltic Pyrobitumens.**—A species of pyrobitumen, including dark colored, comparatively hard and non-volatile solids; composed of hydrocarbons, *substantially free from oxygenated bodies*; sometimes associated with mineral matter, the non-mineral constituents being *infusible* and largely *insoluble* in carbon disulfide. [This definition includes *elaterite* (characteristic rubbery nature and brown streak), *wurtzilite* (conchoidal to hackly fracture; brown streak; depolymerizes on heating, becoming fusible and soluble), *albertite* (conchoidal to hackly fracture; brownish black streak; depolymerizes partially on heating), *impsonite* (hackly fracture; black streak; does not depolymerize on heating) and the *asphaltic pyrobituminous shales*.]

## CHARACTERISTICS

The distinguishing physical and chemical characteristics of the substances enumerated above are given in the following table.

## THERMAL PROPERTIES

An asphalt of 2.12 specific gravity gave the following values for the *thermal conductivity* in joule cm<sup>2</sup> sec<sup>-1</sup> (°C, cm<sup>-1</sup>)<sup>-1</sup>: 0°, 0.0061; 10°, 0.0065; 20°, 0.0070; 30°, 0.0074 (Poensgen, 98, 56: 1653; 12. 60: 27; 16).

According to Kinoshita (380, 39: 497; 16) the *specific heat* of asphalt is 0.22 g-cal per g per °C.



Genus	Species	Member	Sp. gr. at 25°C (of non-mineral matter)*	Penetration at 25°C†	Susceptibility factor‡	Fusibility °C§	Fixed carbon	Solubility in carbon disulfide¶	Non-mineral matter insoluble in carbon disulfide¶	Mineral matter¶¶	Carbenes**	Soluble in 88° naphtha††	Oxygen in non-mineral matter‡‡	Paraffin scale§§	Sulfonation residue	Saponifiable matter¶¶¶
Bitumens	Petroleums															
		Native mineral waxes	0.85-1.00 0.90-1.00	5-10 5	80 100	60 to 95 75 to 95	1-10 2-10	95-100 98-100	0-1 0-2	0-5 0-2	0-3 0-2	75-95 80-100	0-2 3-6	50-90 0-10	90-100 0-10	0-2 50-80
	Native asphalts	Cont'g less than 10 % mineral matter.....	0.95-1.12	0-350	15-100	15 to 165	1-25	60-98	0-40	0-10	0-5	25-95	0-2	0-5	90-100	0-2
		Cont'g more than 10 % mineral matter.....	0.95-1.15	0-150	30-100	15 to 175	5-25	Tr.-90	0-25	10-95	0-5	Tr.-85	0-2	0-5	90-100	0-2
Pyrobitumens	Asphaltites	Gilsonite.....	1.05-1.10	3	100	120 to 175	10-20	90-100	0-1	Tr.-1	0-1/2	40-60	0-2	0-Tr.	85-95	Tr.
		Glance pitch.....	1.10-1.15	5	100	120 to 175	20-30	95-100	0-1	Tr.-5	0-1	20-50	0-2	0-Tr.	85-95	Tr.
	Asphaltic pyrobitumens	Grahamite.....	1.15-1.20	0	100	175 to 320	30-55	45-100	0-5	Tr.-50	0-80	Tr.-50	0-2	0-Tr.	80-95	Tr.
		Elaterite.....	0.90-1.05	Rubbery		Inf.	2-5	10-20	70-90	Tr.-10	Tr.-2	5-10	1-5	0-Tr.	80-90	Tr.-15
Pyrogenous distillates	Non-asphaltic pyrobitumens	Wurtzillite.....	1.05-1.07	5		Inf.	5-25	5-10	80-95	Tr.-10	Tr.-2	Tr.-2	0-2	0-Tr.	90-98	Tr.
		Albertite.....	1.07-1.10	0		Inf.	25-50	2-10	85-98	Tr.-10	Tr.-2	Tr.-2	0-3	0-Tr.	90-98	Tr.
	Pyrogenous waxes	Impsonite.....	1.10-1.25	0		Inf.	50-85	1-6	90-99	Tr.-10	Tr.-2	Tr.-2	0-3	0-Tr.	90-98	Tr.
		Asphaltic pyrobituminous shales.....	1.50-1.75	0		Inf.	2-25***	Tr.-3	15-70	30-85	0-Tr.	0-Tr.	0-3	Tr.-3	90-98	Tr.
Pyrogenous residues	Tars															
		Residual oils.....	0.85-1.05	100-350		-20 to 25	2-10	98-100	0-1/2	0-1/2	0-1	80-99	0-3	0-15	90-100	Tr.-5
	Pyrogenous asphalts	Blown petroleum asphalts.....	0.90-1.07	25-200	8-40	25 to 200	5-20	95-100	0-5	0-1/2	0-10	50-90	2-5	0-10	90-100	Tr.-2
		Residual asphalts.....	1.00-1.17	0-150	40-60	25 to 110	5-40	85-100	0-15	0-1	0-30	25-85	0-2 1/2	0-5	90-100	0-2
Pitches	Sludge asphalts.....	Sludge asphalts.....	1.05-1.20	0-150	40-60	25 to 110	5-30	95-100	0-5	0-1	0-15	60-95	3-7	0-1/2	80-95	0-2
		Wurtzillite asphalt.....	1.04-1.07	5-10	30-40	65 to 150	5-25	98-100	0-1/2	Tr.-2	0-2	50-80	0-2	0-Tr.	90-95	Tr.

\* Am. Soc. Testing Materials, Tentative Standards, 1922: 473, 476. † *Ibid.*, 1921: 728. ‡ Abraham, 66, 11: 683; 11. § Am. Soc. Testing Materials, Standards, 1921: 739. || *Ibid.*, 1921: 766. ¶ Anon., 66, 23 I: 761; 23. \*\* Anon., 66, 23 I: 754; 23. B68, p. 526. †† B68, p. 527. ‡‡ Am. Soc. Testing Materials, Tentative Standards, 1921: 779. §§ B68, p. 536. ¶¶ B68, p. 537. ¶¶¶ B68, p. 547. \*\*\* Calculated on mineral-free basis.

## BITUMINOUS MATERIALS

JOHN M. WEISS AND CHARLES R. DOWNS

## TARS, PITCHES AND DISTILLATES

This section deals with those species of pyrogenous residues known as "tars," together with the products of tar distillation, *i.e.*, "residuals" or "pitches," and "distillates" or "tar oils." These are highly complex materials formed by the pyrogenetic decomposition of various organic materials, so that a particular member or sub-member may vary widely in its physical characteristics.

In the first section are given certain so-called constants in terms of ranges for the various materials. These give general information as to the nature of the various materials. The results are expressed in terms of arbitrary tests which depend upon rigid adherence to details of manipulation; the test methods are those generally used in the United States. The ranges given have been taken partly from the literature, but for the most part from pri-

vate communications from various commercial concerns dealing with the products (2, 5, 6, 11, 16, 18, 19), and certain U. S. Government laboratories (4, 10). Freak results caused by some unusual procedure in the production of a given material have been eliminated so as to make the ranges representative of the materials as they are ordinarily encountered in industry.

In addition, there are reported the available more or less absolute constants that have been determined. As the materials in a given narrow class vary in ordinary tests, so they also vary in these "absolute" constants between samples in the same class; the accuracy of the figures is only moderate, but, in general, adequate to the commercial need which caused the determinations to be made. Blanks indicate that no authentic results are available. Single figures mean that the test of a single sample only could be obtained.

TABLE 1.—TARS

The figures in Table 1 apply to water-free tar. In attempting to identify tars, it is advisable to distill them and test the oils (*See* Table 3.) Methods of testing are given by Weiss (22).  $\eta$  is Engler viscosity, sec for 100 cm<sup>3</sup>; % insol. is the % organic insoluble in C<sub>6</sub>H<sub>6</sub> and C<sub>7</sub>H<sub>8</sub>.

Genus	Species	Member	Sub-member	$d_{15.5}^{15.5}$	$\eta$	% insol.	% fixed carbon	% ash	% tar acids
Tars	Coal tars	Bituminous coal	Coke oven	1.15–1.26	30–100	3–17	14–40	0–0.5	1–4
			Horizontal gas retort	1.25–1.33	150–650	16–40	15–40	0–0.5	1–4
			Inclined gas retort	1.23–1.24	300	15–20	15–40	0–0.5	4–6
			Vertical gas retort	1.12–1.16	25–50	2–5½	15–30	0–0.5	5–11
			Low temperature processes	0.95–1.12	25–50	0–7	5–15	0–1.5	10–30
			Blast furnace	1.15–1.30	80	10–25	10–30	10–15	5–10
			Gas producer	1.12–1.20	100– $\alpha$	5–25	10–35	0–25	3–9
		Cannel coal		0.945		0.2		0.1	9.0
		Lignite		0.85–1.05		0–2	5–20	0–1	5–20
	Petroleum tars	Carburetted water gas		1.06–1.15	25–50	0.2–5.0	10–20	0–0.5	0
		Oil gas		0.95–1.10	25	0–2.0	10–25	0–0.5	0
	Wood tars	Hardwood		1.10–1.21	50	0–5.0	5–20	0–1.0	5–15
		Softwood (pine tars)		1.05–1.15	65	0–7.5	5–15	0–1.0	10–40
	Miscellaneous tars	Bone		0.95–1.05	28	0–5.0	3–15	0–0.5	0.3–40
		Shale		0.85–0.95		0–2.0	5–10	0–1.0	0–2
		Peat		0.90–1.05		0–3.0	5–15	0–1.0	5–15

$d_{15.5}^{15.5}$  of 235–315° fraction (A. S. T. M. distn.): Coke oven, 1.02–1.05; horizontal and inclined gas retort, 1.02–1.04; vertical gas retort, 1.00–1.01; bone tar, 0.950.



TABLE 2.—PITCHES

Method of testing, Weiss (22). The M. P. range given is about the maximum in which they have been known to occur commercially

Genus	Species	Member	Sub-member	Cube M. P.	$d_{15.5}^{15.5}$	% Insol.	% fixed carbon	% ash
Tar pitches	Coal tar pitches	Bituminous coal	Coke oven	30-150	1.20-1.35	8-50	17-60	0-0.5
			Horizontal gas retort	30-100	1.25-1.40	30-55	36-65	0-0.5
			Inclined gas retort	30-100	1.25-1.35	28-37	37-45	0-0.5
			Vertical gas retort	30-150	1.15-1.30	6-30	15-40	0-0.5
			Low temperature processes	30-90	1.00-1.26	2-15	8-22	0-3.0
			Blast furnace	30-100	1.20-1.30	15-35	10-30	10-20
			Gas producer	30-100	1.20-1.35	15-40	25-45	0-2
		Cannel coal		55	1.067	5.3	14.2	0.2
		Lignite coal		30-115	1.05-1.20	3-16	10-40	0-1.0
	Petroleum tar pitches	Carburetted water gas tar		30-150	1.10-1.25	2-25	25-45	0-0.5
		Oil gas tar		30-150	1.15-1.30	2-30	20-35	0-0.5
	Wood tar pitches	Hardwood		40-100	1.20-1.30	5-70	15-35	0-1.0
		Softwood		40-100	1.10-1.20	2-60	10-25	0-1.0
	Miscellaneous tar pitches	Bone		30-125	1.10-1.20	1-20	15-25	0-0.5
		Shale						
		Peat		35-125	1.05-1.15	0-5	10-30	0-1.0
Stearine pitch	Fatty acids				0.90-1.10	0-5	5-35	0-5
Rosin pitch				50-100	1.08-1.15	0-2	10-20	0-1

TABLE 3.—DISTILLATES

Method of testing: Tar acids, Weiss (22);  $d$ ,  $n$ , sulfonation residue, Bateman (3)

	$d_{40}^{60}$				$n_D^{60}$				Sulfonation residue				Tar acids
	235-55°	255-75°	275-95°	295-315°	235-55°	255-75°	275-95°	295-315°	235-55°	255-75°	275-95°	295-315°	Total oil distillate
Coke oven.....	1.01-1.04	1.02-1.06	1.03-1.08	1.06-1.09	1.588-1.609	1.590-1.618	1.594-1.628	1.608-1.635	0-3.5	0-5.0	0-5	0-5	1-12
Horizontal gas retort....	1.01-1.025	1.02-1.04	1.04-1.07	1.06-1.09	1.580-1.596	1.590-1.602	1.598-1.614	1.610-1.628	0-1.5	0-1.5	0-3	0-3	5-20
Inclined gas retort.....	1.005-1.015	1.01-1.035	1.03-1.06	1.04-1.06	1.574-1.593	1.577-1.596	1.586-1.608	1.594-1.623	0.5-4.5	1-7	2-8	3-8	14
Vertical gas retort.....	1.000-1.01	1.01-1.025	1.02-1.05	1.04-1.06	1.53-1.575	1.579	1.587-1.594	1.600-1.612	4-6	5-7	5-6	4-6	20-30
Blast furnace.....	0.94-0.95	0.95	0.94-0.96	0.96-0.98	1.523	1.530	1.534	1.543	17	21	21	19	30
Gas producer.....	0.95		0.98		1.50-1.52				16				10
Lignite.....	0.96	0.96	0.96-0.97	0.97-0.98	1.520	1.528	1.534	1.542	21	25	28	29	30-50
Carburetted water gas...	0.96-1.01	0.965-1.03	0.97-1.07	0.98-1.08	1.558-1.598	1.562-1.602	1.572-1.622	1.578-1.630	0-11	0-13	0-16	0-17	0
Oil gas.....	0.93	0.93	0.93	0.94-0.95	1.533	1.533	1.533	1.530-1.540	26.0	32.0	38.0	34.0	0
Hardwood.....	0.98	0.97			1.500	1.495			7	9			47
Softwood.....	0.98-0.99	0.99	0.99	0.99	1.505	1.514	1.523	1.533	2	3-4	4-5	4.0	15
Bone.....	0.92	0.94	0.95	0.94					12.0	7.4	3.0	0.0	0.5

Low temperature coke oven shows tar acids in total oil distillate 20-56.

## COEFFICIENTS OF CUBICAL EXPANSION

$\alpha = \frac{10^6(V_2 - V_1)}{V_1(t_2 - t_1)}$ . In each case an average figure for use is suggested, with figures showing the maximum deviation of individual samples from the average suggested. For special cases, reference to the original articles is recommended (3, 8, 13, 21, 23). For effect of solids in creosote oil, see (8, 13).

Material	Range °C	$\alpha$ per °C	Max. dev. $\pm$
Water gas tars.....	15-80	655	25
Vertical retort coal tars.....	15-80	640	10
Coke oven coal tars.....	15-80	575	25
Horizontal gas retort coal tars.....	15-80	550	60
Low temperature coal tars.....	15-85	760	15
Coal tar and heavy oils (when liquid)...	15-80	760	40
Water gas tar and heavy oils.....	15-60	770	20
Low temperature tar and heavy oils...	15-85	760	30
Coal tar middle oils.....	15-60	800	20
Gas drip (holder oils).....	15-60	1000	50
Coal tar and water gas tar pitches.....	15-250	460	40
Low temperature tar pitches.....	15-85	660	40

## FLASH POINTS

These represent open cup results (3, 5, 6, 18).

40°C M. P. Coal tar pitch.....	145°C
60°C M. P. Coal tar pitch.....	211°C
Coal tar creosotes.....	70-75°C
Low temperature tars....	100°C $\pm$ 10°C

SPECIFIC HEAT—G-CAL G<sup>-1</sup> DEG.<sup>-1</sup> C

Coal tars—from 0.35 ( $\pm$ .05) at 40°C to 0.45 ( $\pm$ .05) at 200°C. Coal tar oils—0.34 ( $\pm$ .04) at 15°-90°C ((3) and private communications).

## LATENT HEAT OF VAPORIZATION

## Coal tar oils (24)

Temperature range, °C	Heat of vapori- zation, g/cal g <sup>-1</sup>
199-249	84.8
249-296	81.0
296-345	85.1
345-392	73.3
392-438	65.1
438-488	63.1

## VISCOSITY (3, 13.5, 15, 20)

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(For a key to the periodicals see end of volume)

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## EXPLOSIONS AND GASEOUS EXPLOSIVES

WILLIAM A. BONE AND DONALD T. A. TOWNEND

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## IGNITION TEMPERATURE

The ignition temperature of a gaseous mixture is the temperature at which the heat lost by conduction, etc., is more than counterbalanced by the rate at which it is developed by the reaction, the combustion thus becoming self-propellant. This temperature is a function not only of the gaseous mixture employed but also of the means used for heating it. Also, there is often a short "pre-flame" period, during which the combustion is autogenous, but without any actual appearance of flame.

## Experimental Methods

- Mixture passed through tube held at known temperature.
- Mixture rapidly admitted to hot bulb at known temperature. Pre-flame "lag" sometimes determined by this method.
- Bulb containing mixture heated rapidly to definite temperature.
- Mixture passed through small reservoir while temperature was raised until flame at exit tube ran back into it.
- Constituent gases heated separately in concentric tubes, gas

from inner tube being then passed into gas in outer tube. In most recent methods pre-flame "lag" has been controlled.

- Constituent gases heated separately and mixed in open away from surface contact.
  - Mixture adiabatically compressed and temperature calculated from final volume.
  - Mixture adiabatically compressed and temperature calculation based on final pressure experimentally determined. Correct temperature lies between the values calculated by methods G and H.
  - Glass vessel within an iron one, each containing a constituent gas. Glass vessel broken at definite temperature.
  - Small drop of inflammable liquid dropped into air or oxygen maintained at a known temperature.
  - Soap bubble blown with mixture touched by hot wire at known temperature.
- Pressure = 1 atm. unless otherwise noted.



**H<sub>2</sub>**

Method A (41); cf. (7, 9, 10, 16, 17)		Method B		
		(4)		(24)
t°C*	2H <sub>2</sub> + O <sub>2</sub> +	t°C	2H <sub>2</sub> + O <sub>2</sub> +	
605	—	550	—	For
605	H <sub>2</sub>	552–559	H <sub>2</sub>	15% H <sub>2</sub> in air, 590°
611	4H <sub>2</sub>			in 375 cm <sup>3</sup> vessel
617	7H <sub>2</sub>	560–570	3H <sub>2</sub>	and 625° in 9 cm <sup>3</sup>
604	O <sub>2</sub>	530–532	1½O <sub>2</sub>	vessel.
599	2½O <sub>2</sub>			For
594	4O <sub>2</sub>	552–553	4N <sub>2</sub>	60% H <sub>2</sub> in air, 620°
589	4½O <sub>2</sub>	560–595	½CO <sub>2</sub>	in 375 cm <sup>3</sup> vessel
584	7O <sub>2</sub>	562–592	3CO <sub>2</sub>	and 712° in 9 cm <sup>3</sup>
				vessel.

\* All at P = 300 mm.

Method C (18); cf. (6, 9)		Method D (13)	Method F (42)
t°C	2H <sub>2</sub> + O <sub>2</sub> +		
589	—	650° – 2H <sub>2</sub> + O <sub>2</sub>	642° – 2H <sub>2</sub> + O <sub>2</sub>
560	N <sub>2</sub>		
543	2N <sub>2</sub>		
577	3N <sub>2</sub>		
609	4N <sub>2</sub>		

Method E (50, 52, 58); cf. (21, 43): L = lag in sec; (a) = H<sub>2</sub> in O<sub>2</sub>; (b) = H<sub>2</sub> in air

L	(a)	(b)	L	(a)	(b)	L	(a)	(b)	L	(a)	(b)
½	625	630	2	615	619	5	597	602	10	582	585
1	622	625	3	607	613	7	589	592	15	573	577

INFLUENCE OF PRESSURE ON IGNITION TEMPERATURE OF H<sub>2</sub> IN AIR

Method E (50, 52, 58): L = lag in sec; P in mm

P*	75	100	200	400	600	760	1000	1200	1520
L									
½	513	524	558	598	622	630	632	630	628
1	511	521	554	592	614	620	623	621	619
2	509	519	549	581	601	606	609	609	608
3			545	576	592	595	600	600	599

\* For P = 7 atm. the ignition temp. = 611° for 0.5 sec lag.

Method G (50, 51, 58); cf. (20, 26, 28)		Method H (37)		Method I (36)	
t°C*	2H <sub>2</sub> + O <sub>2</sub> +	t°C	2H <sub>2</sub> + O <sub>2</sub> +	t°C	2H <sub>2</sub> + O <sub>2</sub> +
521	—	410†	ca. 4N <sub>2</sub>	412	H <sub>2</sub>
544	H <sub>2</sub>			433	2H <sub>2</sub>
581	2H <sub>2</sub>	For 53% H <sub>2</sub> in air, 460°†		397.5	½O <sub>2</sub>
501	O <sub>2</sub>			407	O <sub>2</sub>
481	3O <sub>2</sub>				
459	7O <sub>2</sub>				
439	15O <sub>2</sub>			Method K (31, 33)	
540	ca. 4N <sub>2</sub>				
468	ca. 3O <sub>2</sub> + 16N <sub>2</sub>				

\* Calc. using γ = 1.4.

† Calc. using γ = 1.32 to allow for cooling losses during compression.

**H<sub>2</sub> + Cl<sub>2</sub>**For Cl<sub>2</sub> + H<sub>2</sub> by method A (9), 430°–440°; method C (9), 240°–270°; in dark, 190° (11).**H<sub>2</sub>S**For 2H<sub>2</sub>S + 3O<sub>2</sub> by method A (9), 315°–320°; method C (9), 250°–270°. For H<sub>2</sub>S, by method E (21), in O<sub>2</sub>, 220°–235°; in air, 346°–379°.**NH<sub>3</sub>**By method E (21), in O<sub>2</sub>, 700°–860°. By method not stated (22), in air, 780°.**CO**

Method B (4): M = 2CO + O <sub>2</sub>				Method E (43); cf. (21) For CO in O <sub>2</sub> , 665° with ½ sec lag; 624° with 10 sec lag For CO in air, 725° with ½ sec lag; 685° with 10 sec lag Method B (24) 20–70 % in air, 610°
t°C	M +	t°C	M +	
645–650	CO	650–657	4N <sub>2</sub>	
630–650	4CO	695–715	3CO <sub>2</sub>	
650–680	O <sub>2</sub>			

For method A and C cf. (9); for method D (13); for method G (19); for method K (31)

**CH<sub>4</sub> Methane**CH<sub>4</sub> + 2O<sub>2</sub>, by method A (9), 650°–730°; by method C (9), 606°–650°. By method D (13), 656°–678°.By method B (4), CH<sub>4</sub> + 2O<sub>2</sub> at 600°–650°; 5CH<sub>4</sub> + 2O<sub>2</sub> at 640°–660°; 10% CH<sub>4</sub> by vol. in air at 730°–790°. (First observation of lags prior to explosion.) Method B\* (23, 24, 40). % = % CH<sub>4</sub> in air; V<sub>15</sub> = temp. in 15 cm<sup>3</sup> vessel, V<sub>275</sub> in 275 cm<sup>3</sup> vessel and V<sub>81</sub> in 81 cm<sup>3</sup> vessel.

%	V <sub>15</sub>	V <sub>275</sub>	%	V <sub>15</sub>	V <sub>275</sub>	%	V <sub>81</sub>	%	V <sub>81</sub>
3	737	680	10	750	710	2	711	8.8	707
6.5	736	675	12	765	710	3	700	10	714
8.0	735	680	16	807	750	5.9	695	11.8	724
						7.0	697	14.4	742

\* The explosion occurs after certain definite time lags.

Method E (43), cf. (21). For CH<sub>4</sub> in O<sub>2</sub>, ½ sec lag, 665°; 10 sec lag, 624°. For CH<sub>4</sub> in air, ½ sec lag, 725°; 10 sec lag, 685°. Method E (50, 52, 58). For CH<sub>4</sub> in air. P = mm pressure; L = lag in sec.

P	100	200	400	600	760	1520	2280	3800	5320
L									
0.5							705	675	653
0.6	815	788	765	753	746	722			
1	804	768	747	737	728	711	695	666	644
2	782	733	717	712	715	690	680	652	633
3	—	715	702	696	694	676	667	640	624

Method E (58). For CH<sub>4</sub> in O<sub>2</sub>. P = mm pressure; L = lag in sec.

P	75	100	200	400	600	760
L						
0.5	727	728	732	720	696	670
0.6	715	716	721	715	688	666
1	694	695	697	692	675	657
2	667	665	660	652	645	641
3		651	643	636	631	629
10		633	621	611	604	602

By method G (58), CH<sub>4</sub> + 3O<sub>2</sub>, 340°; CH<sub>4</sub> + 5O<sub>2</sub>, 345°; CH<sub>4</sub> + 15O<sub>2</sub>, 377°; 7½% CH<sub>4</sub> in air, 428°.**C<sub>2</sub>H<sub>2</sub> Acetylene**By method E (21), in O<sub>2</sub>, 400°–440°; in air, 406°–440°. By method B (24), for 45–55% C<sub>2</sub>H<sub>2</sub> in air, 335°; 20% in air, 400°; 10% in air, 500°.**C<sub>2</sub>H<sub>4</sub> Ethylene**For C<sub>2</sub>H<sub>4</sub> + 3O<sub>2</sub>, method C (9), 530°–606°. By method B (24), for 4.5–6.5% C<sub>2</sub>H<sub>4</sub> in air (vol. vessel = 275 cm<sup>3</sup>), 487°. By method E (21), for C<sub>2</sub>H<sub>4</sub> in O<sub>2</sub>, 500°–519°; in air, 542°–547°. Cf. (9), method A; (13), method D; (31), method K.

**C<sub>2</sub>H<sub>6</sub> Ethane**By method B (47). % = % C<sub>2</sub>H<sub>6</sub> in air (vol. vessel = 85 cm<sup>3</sup>)

%	1.9	2.3	4.05	4.85	5.7	8.15	10.60
t°C	594	571	560	555	550	540	534

For C<sub>2</sub>H<sub>6</sub>, method A, cf. (9); method D (13). By method C (9), for C<sub>2</sub>H<sub>6</sub> + 3.5O<sub>2</sub>, 530°–606°. By method B (24), for 4–8% C<sub>2</sub>H<sub>6</sub> in air (275 cm<sup>3</sup> vessel), 560°.

**C<sub>3</sub>H<sub>8</sub> Propane**By method D (13), in O<sub>2</sub>, 545°–548°. By method E (21), in O<sub>2</sub>, 490°–570°. Method B (47), vol. of vessel = 85 cm<sup>3</sup>

% C <sub>3</sub> H <sub>8</sub> in air.....	1.25	2.50	3.05	4.90	6.50	7.85
t°C.....	588	552	544	525	516	514

**C<sub>4</sub>H<sub>10</sub> n-Butane**Method B (47), vol. of vessel = 85 cm<sup>3</sup>

% n-C <sub>4</sub> H <sub>10</sub> in air.....	1.25	2.00	2.60	3.65	4.85	7.65
t°C.....	569	545	531	515	502	489

**C<sub>4</sub>H<sub>10</sub> Isobutane**For iso-C<sub>4</sub>H<sub>10</sub> by method D (13), in O<sub>2</sub>, 545°–550°.**C<sub>5</sub>H<sub>12</sub> n-Pentane**

For 2–3% C<sub>5</sub>H<sub>12</sub> in air, 512° by method B (24). For 6.7% in air, 320°–336° by method H (37). Method B (47), vol. of vessel = 85 cm<sup>3</sup>.

% C <sub>5</sub> H <sub>12</sub> in air.....	1.5	2.15	2.75	3.75	5.30	7.65
t°C.....	548	532	520	502	486	476

**C<sub>6</sub>H<sub>6</sub> Benzene**

Method	B	J			K
Lit.	(24)	(30)	(38)	(45)	(31, 33)
	In air	In O <sub>2</sub>	In O <sub>2</sub>	In air	
	5%, 587°	566°	570	490	

**C<sub>6</sub>H<sub>14</sub> n-Hexane**

By method H (37), for 6.7% in air, 300°–306°.

**C<sub>7</sub>H<sub>16</sub> n-Heptane**

By method H (37), for 6.7% in air, 285°; (39) 5% in air, 280°(39).

**C<sub>8</sub>H<sub>18</sub> n-Octane**

By method H, for 6.7% in air, 275° (37); 280° (39).

**Petroleum**

Method	B	J			K
Lit.	(24)	(30)		(27)	(31, 33)
	In air		In O <sub>2</sub>	In air	In air
	2.2% 481°	Texas Borneo Mexico	256° 269° 274°	387° 380° 424°	Borneo 400°

**C<sub>2</sub>H<sub>6</sub>O Ethyl Alcohol**

Method	B (in air)			J		
Lit.	(24)	(34)*		(30)	(38)	(45)
	27– 38% 450°	2%, 515–520° 3%, 505°	4%, 455–500° 5%, 480–495°	395°† 518°†	355°‡	360°†

\* Sub-ignition temp.

† In air.

‡ In O<sub>2</sub>.**C<sub>2</sub>H<sub>10</sub>O Ether**

In air by method A (32), 190°; method B (35), 185°–193°; method J (30), 347°. In O<sub>2</sub> by method J (30), 190°.

By method B\* (34), for 4.8% in air, 178°–184°; for 4.1%, 179°–185°; for 3.5%, 180.5°–188°. By method H (39), for 6.6% in air, 212°. Method K, cf. (31, 33).

\* Giving sub-ignition temp. with incomplete combustion.

**CS<sub>2</sub>****Method E (48)**

In O <sub>2</sub> , °C.....	132	128	123	118	114	110	107
In air, °C.....	156	151	145	138	130	124	120
Lag in sec.....	0.5	1	2	3	5	7	10

By method B (5), for CS<sub>2</sub> + 10O<sub>2</sub> at P = 750 mm, 160° with 1–2 sec lag. At P = 300 mm and with 15 sec lag, for CS<sub>2</sub> + 5O<sub>2</sub> + 5N<sub>2</sub>, 155°; for CS<sub>2</sub> + ½O<sub>2</sub> + 8N<sub>2</sub>, 290°. By method F (42), in O<sub>2</sub>, 236°. By method H (39), for 12.5% in air, 253°.

**C<sub>2</sub>N<sub>2</sub> Cyanogen**By Method E (21), in O<sub>2</sub>, 803°–818°**Miscellaneous**

(a) = acetone, (b) = paraffin, (c) = turpentine, (d) = creosote oil, (e) = palm oil, (f) = aldehyde, (g) = aniline, (h) = toluene, (i) = xylene, (j) = methyl alcohol, (k) = amyl alcohol, (l) = anthracene, (m) = naphthalene.

	(a)	(b)	(c)	(d)	(e)	(f)	(g)
Method	B* ‡	J†	J	J*	J*	?*	?*
Lit.	(34)	(30)	(30, 45)	(27)	(27)	(22)	(22)
	4%, 500° 8%, 500°	251°	275°*† 240°*	550°	400°	380°	530°

	(h)	(i)	(j)	(k)	(l)	(m)
Method	J†	?*	J†	J†	J†	J†
Lit.	(38, 30)	(22)	(38)	(38)	(38)	(38)
	563° 516°	500°	500°	315°	472°	500°

\* In air.

† In O<sub>2</sub>.

‡ Satd. at 15°, 505°.

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(For a key to the periodicals see end of volume)

- (1) Davy, 62, 106: 7; 1816. (2) Bunsen, B72. (3) Mitscherlich, 25, 9: 1171; 76. (4) Mallard and Le Chatelier, 34, 91: 825; 80. 51, 1: 173; 82. 15, 4: 274; 83. 27, 39: 2; 83. (5) Turpin, 133, 1890: 776. (6) Krause and Meyer, 13, 264: 85; 91. (7) Freyer and Meyer, 25, 25: 622; 92. (8) Askenasy and Meyer, 13, 269: 49; 92. (9) Freyer and Meyer, 7, 1: 28; 93. (10) Mitscherlich, 25, 26: 160; 93. (11) Mitscherlich, 25, 26: 399; 93. (12) Meyer, 25, 26: 429; 93. (13) Meyer and Munch, 25, 26: 2421; 93. (14) Meyer and Raum, 25, 28: 2904; 94. (15) Gautier and Helier, 34, 122: 566; 96. (16) Helier, 6, 10: 521; 97. (17) Bodenstein, 7, 29: 665; 99. (18) Emich, 57, 29: 1061; 00. (19) Falk, 1, 28: 1517; 06. (20) Falk, 1, 29: 1536; 07. 8, 24: 450; 07. (21) Dixon and Coward, 4, 95: 514; 09. (22) Holm, 92, 26: 273; 13. (23) Taffanel and Le Floch, 34, 156: 1544; 13. (24) Taffanel and Le Floch, 34, 157: 469; 13. (25) Dixon, Bradshaw and Campbell, 4, 100: 2027; 14. (26) Dixon and Crofts, 4, 100: 2036; 14. (27) Constam and Schlöpfer, 98, 57: 39; 14. (28) Crofts, 4, 101: 290, 306; 15. (29) Cassel, 8, 51: 685; 16. (30) Moore, 54, 36: 109; 17. (31) McDavid, 4, 103: 1003; 17. (32) Alilaire, 34, 168: 729; 19. (33) White and Price, 4, 115: 1248; 19. (34) White and Price, 4, 115: 1462; 19. (35) McClelland and Gill, 117, 16: 109; 20. (36) Fiesel, 7, 97: 158; 21. (37) Tizard, 411, 37: 381; 21. (38) Wollers and Emcke, Krupp's Monatsheft, 1921. (39) Tizard and Pye, 3, 44: 79; 22. (40) Mason and Wheeler, 4, 121: 2079; 24. (41) Mitscherlich and Reuter, 93, 121: 53; 22. (42) Wartenburg and Kannenberg, 7, 105: 205; 23. (43) Dixon, 398, 68: 1; 23. (44) Tauss and Schulte, 98, 68: 574; 24. (45) Jentsch, 98, 68: 1150; 24. (46) Ormandy, 358, 10: 335; 24. (47) Mason and Wheeler, 4, 125: 1869; 24. (48) Dixon, 70, 44: 305; 25. (49) David, 133, 1925; 303. (50) Dixon, 133, 1925; 303. (51) Dixon and Harwood, 398, 1925. (52) Dixon and Higgins, 398, 69: 19; 25. (53) Parr, 45, 17: 1215; 25. (54) Coward and Wheeler, Safety in Mines Research Board, Paper No. 8; 25. (55) Naylor and Wheeler, Ibid. No. 9; 25. (56) Tizard and Pye, 3, 1: 1094; 26. (57) Pignot, 34, 182: 376; 26. (58) Dixon, Harwood and Higgins, 83, preprint, 1926. (59) Dixon and Russell, 4, 75: 600; 99.



## ELECTRICAL IGNITION

In the case of electrical ignition and probably also in contact with direct flame or with an incandescent wire, ionization of the gas is an important factor. In the case of electric spark ignition, attempts have been made to determine experimentally the minimum igniting current or spark energy. Unfortunately, however, quantitative values are not easily determined owing to experimental difficulties. Consequently, much of the experimental evidence is of a contradictory nature, so that the part played by ionization in determining the least energy required to inflame a given explosive mixture remains an unknown factor. Representative curves showing least igniting currents are given in Figs. 1 to 4.

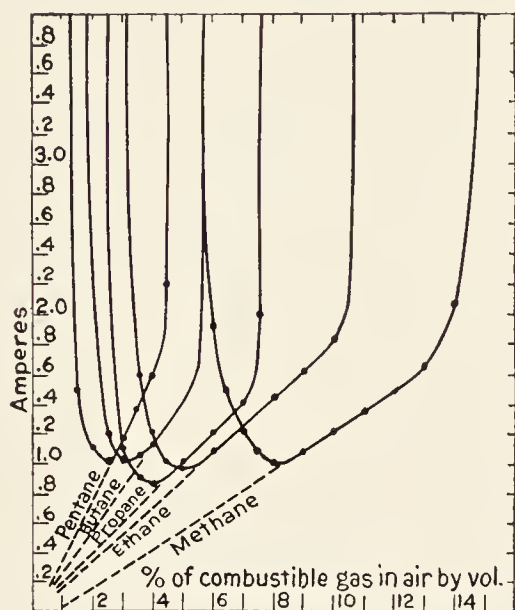


Fig. 1.—Least igniting currents for mixtures in air of members of the paraffin series, using break-sparks. Iron poles. 100 volts (5).

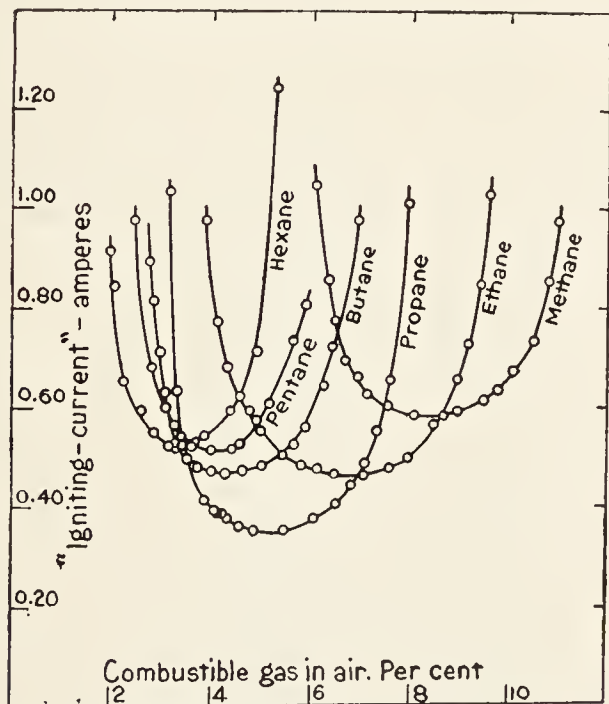


Fig. 2.—Least igniting currents for mixtures in air of members of the paraffin series, using impulsive electrical discharges (33).

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- (1) Thornton, 80, 44 I: 145; 12. 46 II: 112; 13. (2) Thornton, 115, 94: 348; 13. 396, 120: 295; 13. 121, 70: 62; 13. (3) Thomson, 63, 14: 11; 13. (4) Thornton, 121, 71: 1012; 13. (5) Thornton, 5, 90: 272; 14. (6) Thornton, 121, 73: 822; 14. (7) Thornton, 5, 91: 17; 14. (8) Thornton, 3, 28: 734; 14. (9) Hauser, 329, 1916; 521. (10) Thornton, 5, 92: 9; 16. (11) Thornton, 5, 92: 381; 16. (12) Morgan, 115, 102: 427; 16. (13) Morgan, 121, 76: 536; 16. 399, 111: 66; 16. (14) Thornton, 399, 112: 504; 16. (15) Sastry, 4, 109: 523; 16. (16) Wheeler, 4, 111: 130; 17. (17) Wheeler, 4, 111: 411; 17. (18) Wright, 4, 111: 643; 17. (19) Paterson and Campbell, 67, 31: 168; 19.

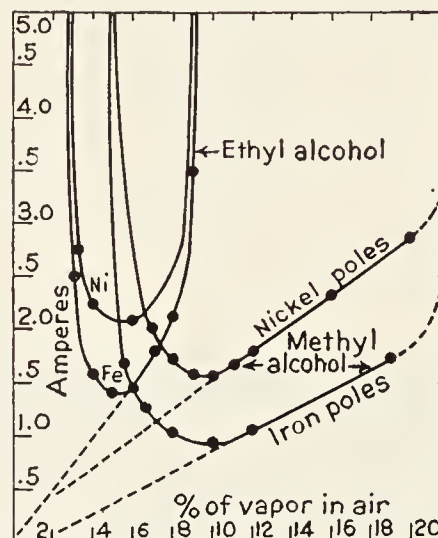


Fig. 3.—Influence of the nature of the pole on the least igniting current for mixtures of methyl or ethyl alcohol vapor with air, using break-sparks. Iron and nickel poles. 100 volts (5).

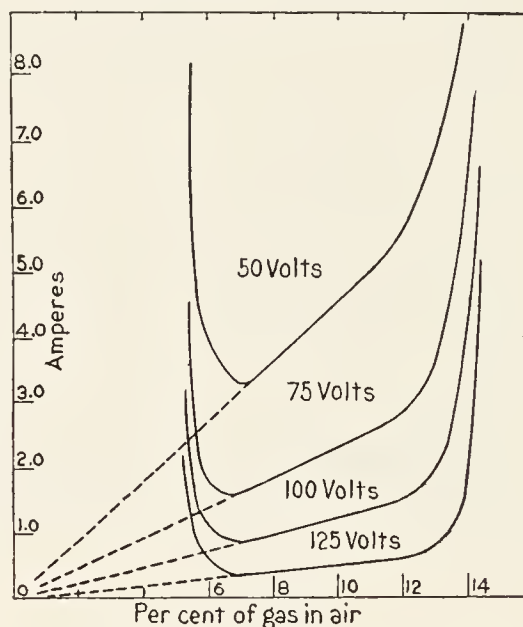


Fig. 4.—Influence of current voltage on the least igniting current for methane-air mixtures, using break-sparks. Iron poles, continuous current (5).

- (20) Thornton, 3, 38: 613; 19. (21) Morgan, 4, 115: 94; 19. (22) Thornton, 3, 40: 345; 20. (23) Thornton, 3, 40: 450; 20. (24) Wheeler, 4, 117: 903; 20. (25) Morgan, 3, 41: 462; 21. (26) Morgan and Wheeler, 4, 119: 239; 21. (27) Thornton, 400, 11: 524; 22. (28) Jones, Morgan and Wheeler, 3, 43: 359; 22. (29) Thornton, 133, 1923; 469. (30) Morgan, 4, 123: 1304; 23. (31) Morgan, 3, 45: 968; 23. (32) Thornton, 46, 62: 481; 24. (33) Wheeler, 4, 125: 1858; 24. (34) Wheeler, 4, 127: 14; 25. (35) Morgan, 3, 49: 323; 25. (36) Thomson, *The Conduction of Electricity through Gases*, London, Cambridge Univ. Press, 1903. (37) Morgan, *Principles of Electric Spark Ignition in Internal Combustion Engines*, London, Lockwood, 1923. (38) Wheeler, *Safety in Mines Research Board. Paper No. 20*; 26. (39) Bone and Weston, 5, 110: 615; 26.

## PRE-FLAME CONDITION

- (40) Kirkby, 3, 7: 223; 04. (41) Kirkby, 3, 13: 289; 07. (42) Kirkby, 5, 85: 151; 11. (43) Lind, 78, 21: 177; 12. (44) Finch and Cowln, 5, 111: 257; 26.

## LIMITS OF INFLAMMABILITY

The limits are given in volume % and apply to atmospheric conditions of temperature and pressure unless otherwise stated. The first value in the limits column is the lowest lower limit, and the second the highest higher limit of the experimentally found values, which usually agree within a few tenths of 1%.

## Abbreviations

$E_v$	Explosion in closed vessel of volume $v$ , cm <sup>3</sup> generally stated.
$Fl_D$	Downward propagation of flame.
$Fl_H$	Horizontal propagation of flame.
$Fl_U$	Upward propagation of flame.
Atm.	Nature of atmosphere.
Exper. condn.	Experimental conditions.
$Tb_x$	Tube whose diameter = $x$ cm.
Sat. <sub>x</sub>	Gases saturated with H <sub>2</sub> O vapor at $x^\circ$ .
$P_{xat}$	Pressure, $x$ atmospheres.
$P_{xmm}$	Pressure, $x$ mm Hg.
All temperatures are in $^\circ\text{C}$ .	

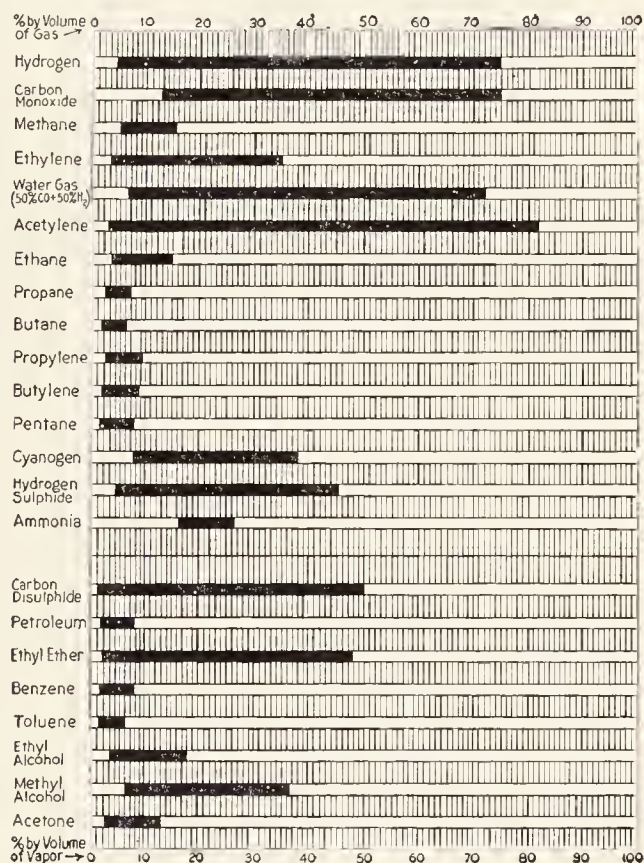


FIG. 4a.—Limits of inflammability of mixtures of gases and vapors with air.

H<sub>2</sub>

Atm.	Limits	Exper. condn.	Lit.
O <sub>2</sub> .....	9.4-91.0	15°	} Fl <sub>H</sub> , Tb <sub>4</sub> , Sat. <sub>17.5</sub> (12)
	9.0-93.3	100°	
Air.....	9.2-65.0	15°	} Fl <sub>H</sub> , Tb <sub>4</sub> , Sat. <sub>17.5</sub> (12)
	9.2-68.5	100°	
Air.....	9.0-62.8	15°	} Fl <sub>H</sub> , Tb <sub>4</sub> , dried by P <sub>2</sub> O <sub>5</sub> (12)
	9.0-68.6	100°	
CO <sub>2</sub> :O <sub>2</sub> .....	11.7-68.4	15°	} Fl <sub>H</sub> , Tb <sub>4</sub> , Sat. <sub>17.5</sub> (12)
79:21.....	11.4-69.4	100°	
Air.....	5.0-72.0	Glass, Tb <sub>7.5</sub> , Fl <sub>U</sub>	(14)
Air.....	10.0-	E <sub>2000</sub>	(18)
Air.....	9.5-66.3		(19)
Air.....	9.45-66.4	E <sub>110</sub> , Sat.	(23)
Air.....	9.73-63.6	Tb <sub>1.4</sub> , Fl <sub>D</sub>	(25)

H<sub>2</sub>—(Continued)

Atm.	Limits	Exper. condn.	Lit.
O <sub>2</sub> .....	5.45-94.7	Sat. <sub>15-18</sub>	(28)
Air.....	8.7 -	} E <sub>100</sub> , Fl <sub>D</sub>	(34)
O <sub>2</sub> .....	8.7 -		(34)
Air.....	9.05-68.6	P <sub>2-3at.</sub>	(36)
	9.28-68.0	P <sub>5-6at.</sub>	(36)
	9.47-67.5	P <sub>10at.</sub>	(36)
Air.....	4.1 -	E <sub>170 000</sub> , Fl <sub>U</sub> , Sat. <sub>17-18</sub>	(39)
Air.....	4.1 -60.0		(51)
Air.....	10 -66.0	E <sub>v</sub>	(52)
Air.....	-74.2	Sat. room	(56)
		15 l vessel	
Air.....	9.4 -65.3	E <sub>120</sub>	(60)
O <sub>2</sub> .....	9.1 -91.7	E <sub>120</sub>	(60)
O <sub>2</sub> :N <sub>2</sub> .....	9.2 -81.2	E <sub>120</sub>	(60)
40.1:59.9			
O <sub>2</sub> :N <sub>2</sub> .....	9.2 -86.4	E <sub>120</sub>	(60)
56.2:43.8			
Air.....	9.46-64.5	Glass pipette	(73)
	9.42-65.9	Glass bulb	(73)
	10.78-59.8	(20°)	} Iron tube (73)
	9.27-67.5	100°	
	8.98-72.2	200°	
	8.62-79.1	300°	
Air.....	4.15-75.0	Fl <sub>U</sub> , Tb <sub>7.5</sub>	(74)
	6.50-	Fl <sub>H</sub> , Tb <sub>7.5</sub>	(74)
	8.8 -74.5	Fl <sub>D</sub> , Tb <sub>7.5</sub>	(74)
Air.....	9.40-71.5	17 ± 3°	} Fl <sub>D</sub> , Tb <sub>2.5</sub> (78)
	9.2 -	50°	
	8.8 -73.5	100°	
	8.3 -	150°	
	7.9 -76.0	200°	
	7.5 -	250°	
	7.1 -79.0	300°	
	6.7 -	350°	
	6.3 -81.5	400°	

H<sub>2</sub>S

Air.....	4.5 -19.0		(51)
Air.....	5.9 -27.2	Fl <sub>H</sub> , Tb <sub>6</sub>	(72)
Air.....	4.30-45.5	Fl <sub>U</sub> , Tb <sub>7.5</sub>	(74)
	5.30-35.0	Fl <sub>H</sub> , Tb <sub>7.5</sub>	(74)
	5.85-21.3	Fl <sub>D</sub> , Tb <sub>7.5</sub>	(74)

NH<sub>3</sub>

Air.....	16.2-27.0	E <sub>500</sub> , sphere	(34)
O <sub>2</sub> .....	15 -80	Found by altering burner mixture	(45)
Air.....	16.1-26.6	Fl <sub>U</sub> , Tb <sub>5</sub> , 18°	(65)
	18.2-25.5	Fl <sub>H</sub> , Tb <sub>5</sub> , 18°	(65)
	22.1-23.3	Fl <sub>D</sub> , Tb <sub>5</sub> , 70°	(65)
	21.0-24.6	Fl <sub>D</sub> , Tb <sub>5</sub> , 90°	(65)
	15.0-28.7	Fl <sub>U</sub> , Tb <sub>5</sub> , 140°	(65)
	17.0-27.5	Fl <sub>H</sub> , Tb <sub>5</sub> , 140°	(65)
	19.9-26.3	Fl <sub>D</sub> , Tb <sub>5</sub> , 140°	(65)
	14.0-30.4	Fl <sub>U</sub> , Tb <sub>5</sub> , 250°	(65)
	15.9-29.6	Fl <sub>H</sub> , Tb <sub>5</sub> , 250°	(65)
	17.8-28.2	Fl <sub>D</sub> , Tb <sub>5</sub> , 250°	(65)
	13.0-32.2	Fl <sub>U</sub> , Tb <sub>5</sub> , 350°	(65)
	14.7-31.1	Fl <sub>H</sub> , Tb <sub>5</sub> , 350°	(65)
	16.0-30.0	Fl <sub>D</sub> , Tb <sub>5</sub> , 350°	(65)
	12.3-33.9	Fl <sub>U</sub> , Tb <sub>5</sub> , 450°	(65)
	13.5-33.1	Fl <sub>H</sub> , Tb <sub>5</sub> , 450°	(65)
	14.4-32.0	Fl <sub>D</sub> , Tb <sub>5</sub> , 450°	(65)



NH<sub>3</sub>.—(Continued)

Atm.	Limits	Exper. condn.	Lit.
O <sub>2</sub> .....	17.1–26.4	Fl <sub>U</sub> , Tb <sub>7.5</sub> , 18°	(65)
	17.4–26.3	Fl <sub>H</sub> , Tb <sub>7.5</sub> , 18°	(65)
	15.3–79.0	Fl <sub>U</sub> , Tb <sub>5</sub> , 18°	(65)
	16.7–79.0	Fl <sub>H</sub> , Tb <sub>5</sub> , 18°	(65)
	14.8–	Fl <sub>H</sub> , Tb <sub>5</sub> , 250°	(65)
	15.8–	Fl <sub>D</sub> , Tb <sub>5</sub> , 250°	(65)
	12.6–	Fl <sub>H</sub> , Tb <sub>5</sub> , 450°	(65)
	13.5–	Fl <sub>D</sub> , Tb <sub>5</sub> , 450°	(65)
	14.8–	Fl <sub>U</sub> , Tb <sub>7.5</sub> , 18°	(65)
	15.6–	Fl <sub>H</sub> , Tb <sub>7.5</sub> , 18°	(65)
	17.3–	Fl <sub>D</sub> , Tb <sub>7.5</sub> , 18°	(65)
CO			
O <sub>2</sub> .....	15.4–94.1	15° } Fl <sub>H</sub> , Tb <sub>4</sub> , Sat. <sub>17.5</sub>	(12)
	14.4–94.8	100° }	
Air.....	14.1–74.8	15° } Fl <sub>H</sub> , Tb <sub>4</sub> , Sat. <sub>17.5</sub>	(12)
	13.0–77.6	100° }	
CO <sub>2</sub> :O <sub>2</sub> } 79:21 }	21.6–73.1	15° } Fl <sub>H</sub> , Tb <sub>4</sub> , Sat. <sub>17.5</sub>	(12)
	20.0–75.1	100° }	
Air.....	13.0–75.0	Fl <sub>U</sub> , Tb <sub>7.5</sub>	(14)
	15.9–74.5	Fl <sub>H</sub> , Tb <sub>4</sub>	(14)
Air.....	19.1–61.7	Tb <sub>0.6</sub>	(17)
	38.0–57.0	Tb <sub>0.3</sub> *	(17)
	16.4–	P <sub>430</sub>	(17)
	18.6–	P <sub>130</sub>	(17)
	27.9–	P <sub>85</sub>	(17)
	14.2–	400°	(17)
	9.3–	470°	(17)
	7.4–	575°	(17)
Air.....	16.0–		(18)
Air.....	17.3–74.8		(19)
Air.....	16.5–75.0	E <sub>110</sub> , Sat.	(23)
Air.....	14.5–	100° } E <sub>100</sub> , Fl <sub>D</sub> , Sat. <sub>15–18</sub>	(34)
O <sub>2</sub> .....	15.7–	100° }	
Air.....	15.9–72.9	P <sub>1at.</sub> , E <sub>1940</sub>	(36)
	18.4–62.0	P <sub>10at.</sub> , Fl <sub>D</sub>	(36)
Air.....	12.5–	E <sub>170 000</sub> , Fl <sub>D</sub> , Sat. <sub>17–18</sub>	(39)
Air.....	12.6–70.0		(51)
Air.....	15.0–73.0	Sat. <sub>room</sub>	(52)
Air.....	–74.2	15 l vessel	(56)
Air.....	15.55–71.0	E <sub>120</sub>	(60)
O <sub>2</sub> .....	16.63–93.6	E <sub>120</sub>	(60)
O <sub>2</sub> :N <sub>2</sub>			
37.8:63.2....	15.85–83.6	E <sub>120</sub>	(60)
50.8:49.2....	15.85–87.7	E <sub>120</sub>	(60)
Air.....	15.75–68.9	Glass pipette	(73)
	15.4–71.6	Glass bulb	(73)
	15.8–63.8	(20°) }	
	14.05–69.6	100° } Iron tube	(73)
	13.80–76.6	200° }	
Air.....	12.8–75.0	Fl <sub>U</sub> , Tb <sub>7.5</sub>	(74)
	13.6–	Fl <sub>H</sub> , Tb <sub>7.5</sub>	(74)
	15.3–70.5	Fl <sub>D</sub> , Tb <sub>7.5</sub>	(74)
Air.....	16.3–70.0	17 ± 3° }	
	15.7–	50° }	
	14.8–71.5	100° }	
	14.2–	150° }	
	13.5–73.0	200° } Fl <sub>D</sub> , Tb <sub>2.5</sub>	(78)
	12.9–	250° }	
	12.4–75.0	300° }	
	12.0–	350° }	
	11.4–77.5	400° }	

\* No mixture can propagate flame through glass Tb &lt; 0.23.

CH<sub>4</sub> Methane

Atm.	Limits	Exper. condn.	Lit.
O <sub>2</sub> .....	6.0–57.3	15° } Fl <sub>H</sub> , Tb <sub>4</sub> , Sat. <sub>17.5</sub>	(12)
	5.7–57.4	100° }	
Air.....	5.7–13.2	15° } Fl <sub>H</sub> , Tb <sub>4</sub> , Sat. <sub>17.5</sub>	(12)
	5.5–13.2	100° }	
	5.8–12.8	15° } Fl <sub>H</sub> , Tb <sub>4</sub> , dried over	(12)
	5.8–13.6	100° } P <sub>2</sub> O <sub>5</sub>	
CO <sub>2</sub> :O <sub>2</sub>			
79:21.....	8.7–11.9	15° } Fl <sub>H</sub> , Tb <sub>4</sub> , Sat. <sub>17.5</sub>	(12)
	8.5–12.2	100° }	
Air.....	5.0–13.0	Fl <sub>U</sub> , Tb <sub>7.5</sub>	(14)
	6.0–11.0	Fl <sub>D</sub> , Tb <sub>7.5</sub>	(14)
Air.....	6.0–	E <sub>2 000</sub>	(18)
Air.....	6.4–12.8		(19)
Air.....	6.1–12.8	E <sub>110</sub> , Sat.	(23)
	6.3–	Fl <sub>D</sub> , Tb <sub>6.2</sub>	(23)
Air.....	5.6–	E <sub>V</sub> , sphere 16 cm diam., cent- ral ignition	(30)
Air.....	6.0–	100° } Fl <sub>D</sub> , E <sub>100</sub> , Sat. <sub>15–18</sub>	(34)
O <sub>2</sub> .....	6.25–	100° }	
Air.....	6.0–13.0	P <sub>1at.</sub> } Fl <sub>D</sub> , E <sub>1940</sub>	(36)
	6.6–14.0	P <sub>10at.</sub> }	
N <sub>2</sub> :O <sub>2</sub> :CO <sub>2</sub>			
81:19.....	5.5–13.5	Limits given are for explo- sion in a large steel bomb	(33)
31:19:50....	8.0–11.3		
83:17.....	5.7–11.8		
40:17:43....	8.3–8.7		
85:15.....	5.9–9.6		
64:15:21....	7.3–7.5		
87:14.....	6.3–7.1		
85:13:2.....	6.6–6.8		
O <sub>2</sub> .....	5.99–		
O <sub>2</sub> :N <sub>2</sub>			
80:20.....	5.95–	E <sub>V</sub> , sphere 16 cm diam. E <sub>V</sub> , sphere 16 cm diam.	(38)
60:40.....	5.90–		
40:60.....	5.82–		
30:70.....	5.77–		
25:75.....	5.76–		
20:80.....	5.78–		
19:81.....	5.84–		
13.4:86.6....	6.41–		
13:87.....	6.63–		
Air.....	5.3–	E <sub>170 000</sub> , Sat. <sub>15–17</sub>	(39)
Air.....		Ignition at:	
	5.6–14.8	Center } E <sub>V</sub> , 16 cm sphere	(41)
	5.4–14.8	Top }	
	6.0–13.4	Bottom }	
	5.4–14.3	Fl <sub>H</sub> , E <sub>V</sub> , Tb <sub>6</sub>	(41)
O <sub>2</sub> :N <sub>2</sub>			
20.9:79.1....	5.60–14.8		(42)
19.2:80.8....	–12.9		
18.3:81.7....	–11.9		
17.0:83.0....	5.80–10.6		
15.8:84.2....	5.83–8.96		
14.9:85.1....	6.15–8.36		
13.9:86.1....	6.35–7.26		
13.5:86.6....	6.50–6.70		
13.2:86.8....	*		
Air.....	5.76–	Fl <sub>D</sub>	(43)
	5.56–	Fl <sub>H</sub>	(43)
	5.52–	Fl <sub>U</sub>	(43)

\* No mixture capable of propagating flame.

CH<sub>4</sub> Methane.—(Continued)

Atm.	Limits	Exper. condn.	Lit.
Air.....	4.9 –	Fl <sub>U</sub>	(47)
	5.7 –	Fl <sub>D</sub>	
	5.5 –	Fl <sub>H</sub>	
Air.....	5.0 –	Fl <sub>U</sub> , E <sub>2800</sub>	(47)
	–13.9	Fl <sub>D</sub> , Tb <sub>30</sub>	(47)
	–15.4	Fl <sub>U</sub> , Tb <sub>30</sub>	(47)
Air.....	5.5 –13.2	Fl <sub>D</sub> , E <sub>100</sub>	(47)
	5.46–	25°, E <sub>100</sub>	(48)
	4.98–	200°, E <sub>700</sub>	(48)
	4.75–	300°, E <sub>100</sub>	(48)
	4.55–	400°, E <sub>100</sub>	(48)
	3.75–	500°, E <sub>100</sub>	(48)
	5.5 –	P <sub>1–5at.</sub> , E <sub>100</sub>	(48)
Air.....	5.6 –14.8		(51)
Air.....	5.5 –14.5		(52)
Air.....	6.00–13.4	20°, Fl <sub>D</sub> , E <sub>V</sub>	(55)
	5.45–13.5	100°, Fl <sub>D</sub> , E <sub>V</sub>	(55)
	5.20–13.6	150°, Fl <sub>D</sub> , E <sub>V</sub>	(55)
	5.05–13.9	200°, Fl <sub>D</sub> , E <sub>V</sub>	(55)
	4.60–14.0	250°, Fl <sub>D</sub> , E <sub>V</sub>	(55)
	4.40–14.3	300°, Fl <sub>D</sub> , E <sub>V</sub>	(55)
	4.15–	350°, Fl <sub>D</sub> , E <sub>V</sub>	(55)
	4.00–14.7	400°, Fl <sub>D</sub> , E <sub>V</sub>	(55)
	3.65–15.4	500°, Fl <sub>D</sub> , E <sub>V</sub>	(55)
	3.35–16.4	600°, Fl <sub>D</sub> , E <sub>V</sub>	(55)
	3.25–18.8	700°, Fl <sub>D</sub> , E <sub>V</sub>	(55)
	–23.6	750°, Fl <sub>D</sub> , E <sub>V</sub>	(55)
	–29.0	800°, Fl <sub>D</sub> , E <sub>V</sub>	(55)
	6.00–13.0	P <sub>750</sub> , Fl <sub>D</sub> , E <sub>V</sub>	(55)
	6.05–13.2	P <sub>1250</sub> , Fl <sub>D</sub> , E <sub>V</sub>	(55)
	–13.4	P <sub>2100</sub> , Fl <sub>D</sub> , E <sub>V</sub>	(55)
	6.20–13.6	P <sub>2900</sub> , Fl <sub>D</sub> , E <sub>V</sub>	(55)
	6.25–	P <sub>3350</sub> , Fl <sub>D</sub> , E <sub>V</sub>	(55)
	–13.8	P <sub>3750</sub> , Fl <sub>D</sub> , E <sub>V</sub>	(55)
	6.40–14.1	P <sub>4650</sub> , Fl <sub>D</sub> , E <sub>V</sub>	(55)
Air.....	–15.4	15 l vessel, Sat. room	(56)
O <sub>2</sub> :N <sub>2</sub>			
13.7:86.3....	6.4 –6.9	Fl <sub>H</sub> , Tb <sub>2.5</sub>	(58)
17.0:83.0....	6.1 –8.9	Fl <sub>H</sub> , Tb <sub>2.5</sub>	
21.0:79.0....	5.8 –13.3	Fl <sub>H</sub> , Tb <sub>2.5</sub>	
33.0:67.0....	5.8 –25.1	Fl <sub>H</sub> , Tb <sub>2.5</sub>	
50.0:50.0....	5.8 –38.8	Fl <sub>H</sub> , Tb <sub>2.5</sub>	
66.0:34.0....	5.8 –47.5	Fl <sub>H</sub> , Tb <sub>2.5</sub>	
O <sub>2</sub> .....	5.7 –59.2	Fl <sub>H</sub> , Tb <sub>2.5</sub>	(58)
Air.....	6.05–12.1	E <sub>120</sub>	(60)
O <sub>2</sub> .....	6.39–52.1	E <sub>120</sub>	(60)
O <sub>2</sub> :N <sub>2</sub>			
45.2:54.8....	6.26–29.7	E <sub>120</sub>	(60)
62.2:37.8....	6.30–38.6	E <sub>120</sub>	
86.3:13.7....	6.44–47.8	E <sub>120</sub>	
Air.....	6.12–13.6	Glass pipette	(73)
	5.82–13.6	Glass bulb	(73)
	6.25–12.8	(20°)	(73)
	6.02–13.9	100°	
	5.91–14.1	200°	
	5.80–14.1	300°	
Air.....	5.35–14.9	Fl <sub>U</sub> , Tb <sub>7.5</sub>	(74)
	5.40–14.0	Fl <sub>H</sub> , Tb <sub>7.5</sub>	(74)
	5.95–13.4	Fl <sub>D</sub> , Tb <sub>7.5</sub>	(74)
Air.....	6.30–12.9	17 ± 3°	(78)
	6.20–	50°	
	5.95–13.7	100°	
	5.75–14.1	150°	

CH<sub>4</sub> Methane.—(Continued)

Atm.	Limits	Exper. condn.	Lit.
	5.5 –14.6	200°	(78)
	5.30–	250°	
Air.....	5.10–15.5	300°	
	4.95–	350°	
	4.80–16.6	400°	
	4.55–	450°	(75)
Air.....	5.4 –14.1	E <sub>V</sub> , Tb <sub>1.5</sub>	
Air +			
0.8% C <sub>2</sub> H <sub>2</sub> Cl <sub>2</sub>	7.35–10.2		(75)
0.8% C <sub>2</sub> H <sub>2</sub> Cl <sub>4</sub>	7.15–9.2		
1.0% C <sub>2</sub> HCl <sub>5</sub>	5.95–10.3		
20% C <sub>2</sub> H <sub>2</sub> Cl <sub>2</sub>	*		
5.5% C <sub>2</sub> HCl <sub>3</sub>	*		
8.5% CCl <sub>4</sub> ...	9.0 –9.9		
12.2% CCl <sub>4</sub> ..	*		

\* No propagation of flame.

See also p. 191.

C<sub>2</sub>H<sub>2</sub> Acetylene

Air.....		Fl <sub>H</sub> , Tb <sub>0.05</sub>	(13)
	7.7 –10.0	Fl <sub>H</sub> , Tb <sub>0.03</sub>	(13)
	5.0 –15.0	Fl <sub>H</sub> , Tb <sub>0.2</sub>	(13)
	4.5 –25.0	Fl <sub>H</sub> , Tb <sub>0.4</sub>	(13)
	4.0 –40.0	Fl <sub>H</sub> , Tb <sub>0.6</sub>	(13)
	3.5 –55.0	Fl <sub>H</sub> , Tb <sub>2.0</sub>	(13)
	3.1 –62.0	Fl <sub>H</sub> , Tb <sub>3.0</sub>	(13)
	2.9–64.0	Fl <sub>H</sub> , Tb <sub>4.0</sub>	(13)
Air.....	2.8 –65.0	{ Continuous propagation,	(18)
O <sub>2</sub> .....	2.8 –93.0	{ large vol.	
Air.....	3.8 –40.0		(19)
Air.....	3.0 –82.0	Fl <sub>D</sub> , Tb <sub>7.5</sub>	(14)
Air.....	3.35–52.3	E <sub>110</sub> , Sat.	(23)
Air.....	1.53–58.7	Fl <sub>D</sub> , Tb <sub>1.4</sub>	(25)
Air.....	2.82–51.7	Fl <sub>D</sub> , E <sub>100</sub>	(46)
	–73.0	Fl <sub>U</sub> , E <sub>2800</sub>	(46)
	2.98–	Fl <sub>U–D</sub> , E <sub>2800</sub>	(46)
	2.53–	Fl <sub>U</sub> , E <sub>28317</sub>	(46)
	2.87–	Fl <sub>D</sub> , E <sub>28317</sub>	(46)
Air.....	3.0 –46.0		(51)
Air.....	3.0 –73.0		(52)
Air.....	3.4 –52.5	E <sub>120</sub>	(60)
O <sub>2</sub> .....	3.4 –90.0	E <sub>120</sub>	(60)
O <sub>2</sub> :N <sub>2</sub>			
40.5:59.5....	3.4 –74.4	E <sub>120</sub>	(60)
58.0:42.0....	3.4 –82.4	E <sub>120</sub>	
78.5:21.5....	3.4 –87.4	E <sub>120</sub>	
Air.....	2.68–	Glass pipette	(73)
	2.39–	Glass bulb	(73)
	3.12–	(20°)	(73)
	1.95–	100°	
	1.95–	200°	
Air.....	2.60–80.5	Fl <sub>U</sub> , Tb <sub>7.5</sub>	(74)
	2.68–78.5	Fl <sub>H</sub> , Tb <sub>7.5</sub>	(74)
	2.78–71.0	Fl <sub>D</sub> , Tb <sub>7.5</sub>	(74)
Air.....	2.90–55.0	17 ± 3°	(78)
	2.83–59.0	50°	
	2.68–65.0	100°	
	2.52–73.0	150°	
	2.39–81.0	200°	
	2.30–	250°	
	2.19–	300°	



**C<sub>2</sub>H<sub>4</sub> Ethylene**

Atm.	Limits	Exper. condn.	Lit.
Air.....	4.0 -22.0	Fl <sub>U</sub> , Tb <sub>7.5</sub>	(14)
Air.....	4.1 -14.6	E <sub>110</sub> , Sat.	(23)
	3.4 -	Fl <sub>D</sub> , Tb <sub>6.2</sub> , Sat.	(23)
Air.....	5.7 -17.5		(51)
Air.....	3.8 -14.2	E <sub>120</sub>	(60)
O <sub>2</sub> .....	4.0 -62.0	E <sub>120</sub>	(60)
O <sub>2</sub> :N <sub>2</sub>			
40.4:59.6....	4.0 -47.7	E <sub>120</sub>	(60)
74.7-25.3....	4.0 -56.4	E <sub>120</sub>	
Air.....	3.4 -14.1	Fl <sub>H</sub> , Tb <sub>2.5</sub>	(62)
	3.6 -13.7	Fl <sub>D</sub> , Tb <sub>2.5</sub>	(62)
	3.2 -25.6	Fl <sub>U</sub> , Tb <sub>2.5</sub>	(62)
Air.....	3.52-	Glass pipette	(73)
	3.34-	Glass bulb	(73)
	3.69-	(20°)	(73)
	3.22-	100°	
	3.40-	200°	
Air.....	3.02-34.0	Fl <sub>U</sub> , Tb <sub>7.5</sub>	(74)
	3.20-23.7	Fl <sub>H</sub> , Tb <sub>7.5</sub>	(74)
	3.33-15.5	Fl <sub>D</sub> , Tb <sub>7.5</sub>	(74)
Air.....	3.45-13.7	17 ± 3°	(78)
	3.35-	50°	
	3.20-14.1	100°	
	3.10-	150°	
	2.95-14.9	200°	
	2.85-15.7	250°	
	2.75-17.9	300°	
	2.60-	350°	
	2.50-	400°	

**C<sub>2</sub>H<sub>6</sub> Ethane**

Air.....	3.10-	{ Center ignit. E <sub>v</sub> , sphere 16 cm diam. }	(30)
Air.....	3.10-10.7		(51)
Air.....	2.5 -5.0		(52)
Air.....	3.3 -10.6	Fl <sub>H</sub>	(58)
Air.....	3.9 -9.6	Tb <sub>2.5</sub>	(60)
O <sub>2</sub> .....	3.9 -46.2	Tb <sub>2.5</sub>	(60)
O <sub>2</sub> :N <sub>2</sub>			
37.4:63.6....	3.80-21.9	E <sub>120</sub>	(60)
59.5:40.5....	3.90-33.6	E <sub>120</sub>	
74.7:25.3....	3.80-39.7	E <sub>120</sub>	
Air.....	3.12-15.0	Fl <sub>U</sub> , Tb <sub>7.5</sub>	(74)
	3.15-12.9	Fl <sub>H</sub> , Tb <sub>7.5</sub>	(74)
	3.26-10.2	Fl <sub>D</sub> , Tb <sub>7.5</sub>	(74)

**C<sub>3</sub>H<sub>6</sub> Propylene**

Air.....	2.18-9.7	Fl <sub>U</sub> , Tb <sub>7.5</sub>	(74)
	2.22-9.3	Fl <sub>H</sub> , Tb <sub>7.5</sub>	(74)
	2.26-7.4	Fl <sub>D</sub> , Tb <sub>7.5</sub>	(74)

**C<sub>3</sub>H<sub>8</sub> Propane**

Air.....	2.15-	{ Center ignit. E <sub>v</sub> , sphere 16 cm diam. }	(30)
Air.....	2.17-7.35		(51)
Air.....	2.4 -7.3	Fl <sub>H</sub> , Tb <sub>2.5</sub>	(58)

**C<sub>4</sub>H<sub>8</sub> Butylene**

Air.....	1.70-9.0	Fl <sub>U</sub> , Tb <sub>7.5</sub>	(74)
	1.75-9.0	Fl <sub>H</sub> , Tb <sub>7.5</sub>	(74)
	1.80-6.3	Fl <sub>D</sub> , Tb <sub>7.5</sub>	(74)

**C<sub>4</sub>H<sub>10</sub> n-Butane**

Air.....	1.60-	{ Center ignit. E <sub>v</sub> , sphere 16 cm diam. }	(28)
Air.....	1.55-5.7		(51)
Air.....	1.9- 6.5	Fl <sub>H</sub> , Tb <sub>2.5</sub>	(58)

**C<sub>5</sub>H<sub>12</sub> n-Pentane**

Atm.	Limits	Exper. condn.	Lit.
Air.....	1.1 -		(18)
Air.....	1.35-	E <sub>v</sub> , sphere 16 cm diam.	(30)
Air.....	2.4 -4.9	E <sub>110</sub> , Sat.	(23)
Air.....	1.35-4.5		(51)
Air.....	1.6 -5.4	Fl <sub>H</sub> , Tb <sub>2.5</sub>	(58)
Air.....	1.42-8.0	Fl <sub>U</sub> , Tb <sub>7.5</sub>	(74)
	1.44-7.45	Fl <sub>H</sub> , Tb <sub>7.5</sub>	(74)
	1.48-4.64	Fl <sub>D</sub> , Tb <sub>7.5</sub>	(74)
Air.....	1.53-4.5	17 ± 3°	(78)
	1.50-	50°	
	1.44-4.75	100°	
	1.39-4.90	150°	
	1.34-5.05	200°	
	1.30-	250°	
	1.22-5.35	300°	

**C<sub>5</sub>H<sub>12</sub> Isopentane**

Air.....	1.30-	{ Center ignit. E <sub>v</sub> , sphere 16 cm diam. }	(30)
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**C<sub>6</sub>H<sub>6</sub> Benzene**

Air.....	1.5 -	E <sub>2000</sub>	(18)
Air.....	1.4 -4.7	E <sub>2000</sub>	(21)
Air.....	2.65-6.5	E <sub>110</sub>	(23)
	1.4-	Fl <sub>D</sub> , Tb <sub>6.2</sub>	(23)
Air.....	1.5 -8.0		(51)
Air.....	2.6 -7.2	E <sub>120</sub>	(60)
O <sub>2</sub> .....	2.6 -30.1	E <sub>120</sub>	(60)
O <sub>2</sub> :N <sub>2</sub>			
40.5:59.5....	-15.5	E <sub>120</sub>	(60)
58.0:42.0....	2.6 -21.0	E <sub>120</sub>	
78.5:21.5 ...	-27.5	E <sub>120</sub>	
Air.....	1.41-7.45	Fl <sub>U</sub>	(64)
	1.46-5.55	Fl <sub>D</sub>	

**C<sub>6</sub>H<sub>14</sub> Hexane**

Air.....	1.3-	E <sub>2000</sub>	(18)
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**C<sub>7</sub>H<sub>8</sub> Toluene**

Air.....	1.3 -	E <sub>2000</sub>	(18)
Air.....	1.4 -	E <sub>2000</sub>	(21)
Air.....	1.27-6.75	Fl <sub>U</sub>	(64)
	1.28-4.60	Fl <sub>D</sub>	

**C<sub>7</sub>H<sub>16</sub> Heptane**

Air.....	1.1-	E <sub>2000</sub>	(18)
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**C<sub>8</sub>H<sub>18</sub> Octane**

Air.....	1.0-	E <sub>2000</sub>	(18)
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**Petroleum**

Air.....	2.4 -4.9	E <sub>110</sub>	(23)
	1.1 -	Fl <sub>D</sub> , Tb <sub>6.2</sub>	(23)
Air.....	2.94-8.22	E <sub>v</sub> , 60° fraction	(40)
Air.....	1.9 -5.3	Fl <sub>D</sub> , E <sub>100</sub>	(48)
	1.5 -6.4	Fl <sub>U</sub> , E <sub>100</sub>	(48)
	1.50-	23°	(48)
	1.42-	200°	(48)
	1.22-	300°	(48)
	1.02-	400°	(48)
Air.....	1.5 -6.0	E <sub>2300</sub>	(51)
Air.....	1.8 -5.15	E <sub>120</sub>	(60)
O <sub>2</sub> .....	1.9 -28.8	E <sub>120</sub>	(60)

## Petroleum.—(Continued)

Atm.	Limits	Exper. condn.	Lit.
O <sub>2</sub> : N <sub>2</sub>			
44.0:56.0....	1.8 -14.1	E <sub>120</sub>	(60)
59.5:40.5....	2.1 -19.2	E <sub>120</sub>	
74.7:25.3....	1.9 -28.8	E <sub>120</sub>	

CH<sub>4</sub>O Methyl Alcohol

Air.....	5.5 -21.0		(51)
Air.....	7.8 -18.0		(21)
Air.....	6.0 -		(18)
Air.....	7.05-36.5	Fl <sub>U</sub>	(64)
	7.45-26.5	Fl <sub>D</sub>	

C<sub>2</sub>H<sub>4</sub>O Acetaldehyde

Air.....	3.97-57.0	Fl <sub>U</sub>	(64)
	4.27-13.4	Fl <sub>D</sub>	

C<sub>2</sub>H<sub>6</sub>O Ethyl Alcohol

Air.....	3.07-		(18)
Air.....	4.0 -		(21)
Air.....	3.95-13.7	E <sub>110</sub>	(23)
Air.....	4.0 -13.7		(29)
Air.....	2.8 -9.5		(51)
Air.....	3.56-18.0	Fl <sub>U</sub>	(64)
	3.74-11.5	Fl <sub>D</sub>	
Air.....	5.02-	Fl <sub>U</sub>	(56)
	5.18-	Fl <sub>H</sub>	
	5.21-	Fl <sub>D</sub>	(56)
	4.24-19.0	Fl <sub>U</sub>	
	4.32-13.8	Fl <sub>H</sub>	(56)
	4.44-11.5	Fl <sub>D</sub>	
	4.16-	Fl <sub>U</sub>	(56)
	4.37-	Fl <sub>H</sub>	
	4.23-	Fl <sub>D</sub>	

C<sub>3</sub>H<sub>6</sub>O Acetone

Air.....	2.9 -		(18)
Air.....	2.7 -		(21)
Air.....	5.0 -12.0		(29)
Air.....	2.15- 9.7	Fl <sub>U</sub>	(52)
	2.35- 8.5	Fl <sub>D</sub>	(52)
Air.....	2.3 - 7.5	Fl <sub>U</sub>	(56)
	2.4 - 6.7	Fl <sub>H</sub>	
	2.75- 6.5	Fl <sub>D</sub>	(56)
	2.2 - 9.5	Fl <sub>U</sub>	
	2.25- 9.3	Fl <sub>H</sub>	(56)
	2.40- 8.3	Fl <sub>D</sub>	
	2.15- 9.7	Fl <sub>U</sub>	(56)
	2.20- 9.5	Fl <sub>H</sub>	
	2.35- 8.5	Fl <sub>D</sub>	(56)
	2.88-12.4	Fl <sub>U</sub>	
	2.89-12.4	Fl <sub>H</sub>	(56)
	3.11-10.9	Fl <sub>D</sub>	
Air.....	2.89-13.0	Fl <sub>U</sub>	(64)
	2.93- 8.6	Fl <sub>D</sub>	
Air.....	3.59- 9.6	Glass pipette	(73)
	4.03- 8.5	Glass bulb	(73)
	3.68- 8.6	(20°)	(73)
	3.30-10.1	100°	

C<sub>3</sub>H<sub>6</sub>O Allyl Alcohol

Air.....	3.04		(18)
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C<sub>3</sub>H<sub>7</sub>O *n*-Propyl Alcohol

Air.....	2.55-	E <sub>2000</sub>	(18)
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C<sub>3</sub>H<sub>8</sub>O Isopropyl Alcohol

Atm.	Limits	Exper. condn.	Lit.
Air.....	2.65-	E <sub>2000</sub>	(18)

C<sub>4</sub>H<sub>8</sub>O Ethylmethyl Ketone

Air.....	1.97-10.1	Fl <sub>U</sub>	(64)
	2.05- 7.6	Fl <sub>D</sub>	

C<sub>4</sub>H<sub>8</sub>O<sub>2</sub> Ethyl Acetate

Air.....	2.26-11.4	Fl <sub>U</sub>	(64)
	2.33- 7.1	Fl <sub>D</sub>	

C<sub>4</sub>H<sub>10</sub>O Ether

Air.....	1.9 -		(18)
Air.....	1.8 - 5.2		(21)
Air.....	2.75- 7.7	E <sub>110</sub>	(23)
	1.6 -	Fl <sub>D</sub> , Tb <sub>6.2</sub>	(23)
Air.....	0.59-0.195*		(25)
Air.....	2.7 - 7.7		(29)
Air.....	2.35-18.5	Fl <sub>U</sub>	(56)
	2.38- 6.2	Fl <sub>H</sub>	
	2.34- 6.3	Fl <sub>D</sub>	(56)
	1.93-15.8	Fl <sub>U</sub>	
	2.05- 8.0	Fl <sub>H</sub>	(56)
	2.15- 6.2	Fl <sub>D</sub>	
	1.93-17.1	Fl <sub>U</sub>	(56)
	2.05-13.0	Fl <sub>H</sub>	
	2.15- 7.5	Fl <sub>D</sub>	(56)
	1.73-23.3	Fl <sub>U</sub>	
	1.93-22.3	Fl <sub>H</sub>	(56)
	1.80- 6.5	Fl <sub>D</sub>	
	1.87-	P <sub>770</sub> , Fl <sub>H</sub>	(56)
	-12.9	P <sub>751</sub> , Fl <sub>H</sub>	(56)
	-10.5	P <sub>600</sub> , Fl <sub>H</sub>	(56)
	- 9.2	P <sub>520</sub> , Fl <sub>H</sub>	(56)
	1.88-	P <sub>460</sub> , Fl <sub>H</sub>	(56)
	- 8.2	P <sub>450</sub> , Fl <sub>H</sub>	(56)
	- 7.8	P <sub>400</sub> , Fl <sub>H</sub>	(56)
	1.92- 7.3	P <sub>300</sub> , Fl <sub>H</sub>	(56)
	2.08- 6.8	P <sub>200</sub> , Fl <sub>H</sub>	(56)
	2.33- 6.1	P <sub>100</sub> , Fl <sub>H</sub>	(56)
	2.99- 5.0	P <sub>50</sub> , Fl <sub>H</sub>	(56)
	- 6.2	P <sub>600</sub> , Fl <sub>D</sub>	(56)
	- 6.2	P <sub>300</sub> , Fl <sub>D</sub>	(56)
	- 5.9	P <sub>200</sub> , Fl <sub>D</sub>	(56)
	- 5.5	P <sub>100</sub> , Fl <sub>D</sub>	(56)
		P <sub>50</sub>	(56)
Air.....	1.71-48.0	Fl <sub>U</sub>	(64)
	1.85- 6.4	Fl <sub>D</sub>	
Air.....	2.26-6.90	Glass pipette	(73)
	2.38-6.51	Glass bulb	(73)
	2.34-6.15	(20°)	(73)
	1.97-	100°	
	1.63-	200°	

\* Gm per l.

C<sub>4</sub>H<sub>10</sub>O Isobutyl Alcohol

Air.....	1.68-	E <sub>2000</sub>	(18)
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CS<sub>2</sub>

Air.....	1.94-		(18)
Air.....	4.1 -		(21)
Air.....	2.5 -45.0		(51)
Air.....	1.06-50.0	Fl <sub>U</sub>	(64)
	1.91-35.0	Fl <sub>D</sub>	



CS<sub>2</sub>.—(Continued)

Atm.	Limits	Exper. condn.	Lit.
Air.....	2.11–31.7	Glass pipette	(73)
	2.22–31.2	Glass bulb	(73)
	3.38–29.2	(20°)	(73)
	1.35–33.1	100° } Iron tube	

C<sub>2</sub>N<sub>2</sub> Cyanogen

Air.....	7.6–38.0		(51)
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C<sub>6</sub>H<sub>5</sub>N Pyridine

Air.....	1.81–12.4	Fl <sub>U</sub>	Wide tube	(64)
	1.88–7.2	Fl <sub>D</sub>		

C<sub>2</sub>H<sub>5</sub>NO<sub>3</sub> Ethyl Nitrate

Air.....	3.01–7.5	Fl <sub>U</sub>	Wide tube	(64)
	3.83–15.1	Fl <sub>D</sub>		

Water Gas (50% H<sub>2</sub>, 50% CO)

Air.....	12.5–66.5		(19)
Air.....	12.4–66.8	E <sub>110</sub> , Sat.	(23)
	12.3–	Fl <sub>D</sub> , Tb <sub>6.2</sub>	(23)

Water Gas (49.45% H<sub>2</sub>, 47.90% CO, 2.65% air)

Air.....	12.4–66.2	E <sub>120</sub>	(60)
O <sub>2</sub> .....	12.6–92.1	E <sub>120</sub>	(60)
O <sub>2</sub> :N <sub>2</sub>			
38.6:61.4....	12.5–81.3	E <sub>120</sub>	(60)
52.7:47.3....	12.6–86.1	E <sub>120</sub>	

## Mixtures of Combustible Gases (56)

Vol. compn.		Limits	
H <sub>2</sub>	:CO:CH <sub>4</sub>		
100		4.1	–71.5
75	: 25	4.7	–
50	: 50	6.05	–71.8
25	: 75	8.2	–
10	: 90	10.8	–
100		12.5	–73.0
90	: 10	11.0	–
75	: 25	9.5	–
50	: 50	7.7	–22.8
40	: 60	7.2	–
25	: 75	6.4	–
100		5.6	–15.1
25	: 75	4.7	–
50	: 50	4.6	–
75	: 25	4.1	–
90	: 10	4.1	–
33	: 33: 33	5.7	–29.9
55	: 15: 30	4.7	–
48.5	: 51.5	–33.6	

## Relative Limiting Igniting Pressures (89)

Below which, under the same sparking conditions, explosive mixtures would not ignite; *P* = limiting ignition pressure in mm Hg.

% H <sub>2</sub> in O <sub>2</sub>	<i>P</i>	% CO in O <sub>2</sub>	<i>P</i>
92.3	285	94.0	>400
91.7	341	93.9	75
88.9	212	92.5	108
85.7	183	91.0	99
80.0	149	88.9	81
75.0	123	85.7	78
66.7	103	80.0	55
50.0	66	75.0	50

% H <sub>2</sub> in O <sub>2</sub>	<i>P</i>	% CO in O <sub>2</sub>	<i>P</i>
40.0	53	66.7	50
36.7	53	50.0	30
33.3	45	40.0	26
25.0	52	37.5	24
16.7	54	35.3	27
11.8	57	33.3	32
9.1	72	25.0	74
8.8	68*	20.0	92
6.7	80*	18.4	106
		17.0	124
		16.0	135
		15.0	148
		14.3	340
		14.0*	
		13.8*	

\* Incomplete combustion.

## LITERATURE

(For a key to the periodicals see end of volume)

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## LIMITING PRESSURES

- (<sup>84</sup>) Meyer and Seubert, 4, 45: 581; 84. (<sup>85</sup>) Dixon, 62, 175: 634; 84. (<sup>86</sup>) De Hemptinne, 186, 761; 02. (<sup>87</sup>) Fischer and Wolf, 25, 44: 2956; 11. (<sup>88</sup>) Coward, Cooper and Warburton, 4, 101: 2278; 12. (<sup>89</sup>) Coward, Cooper and Jacobs, 4, 105: 1069; 14. (<sup>90</sup>) Stavenhagen and Schuchard, 92, 33: 286; 20. (<sup>91</sup>) Stavenhagen and Schuchard, 92, 34: 114; 21.

## RELATIVE INFLAMMABILITIES

- (<sup>92</sup>) Emich, 57, 18: 6; 97. (<sup>93</sup>) Emich, 57, 19: 299; 98.

## PROPAGATION OF FLAME

## The "Uniform Movement" and Attendant Phenomena

Given certain conditions, an initial "slow uniform flame movement" can usually be effected in a gaseous explosive medium; its velocity is, however, dependent upon (1) the composition of the mixture, (2) its temperature and pressure, (3) the nature and dimensions of the containing vessel (in case of a tube, the diameter being the important dimension) and (4) the source and character of ignition. It is usually determined experimentally by igniting each explosive mixture with the same type of flame at the open end of a tube which is closed at the other end.

The flame movement so initiated usually proceeds at uniform velocity for a certain short distance, and its termination is marked by a period of accelerated vibrational flame movement, which may in some cases give rise to detonation. In other cases, however, it seems to be succeeded abruptly by detonation.

Recently attempts have been made to establish a so-called "law of flame speeds" for complex combustible gaseous mixtures, e.g., coal-gas and air, on the supposition that in such cases the observed flame speed is caused by the oxygen or combustible gas (whichever of the two is in defect) dividing itself during the combustion so as to form a series of explosive mixtures (of each single component combustible gas with oxygen) giving the same flame speed. This, however, seems a fundamentally wrong view of things.

## Abbreviations and Units

Tb<sub>x</sub>. A tube of diameter x cm was used in experiment. The values given in the tables are the velocities of propagation of flame in cm/sec for the mixtures noted. All gas percentages are in volume %.

H<sub>2</sub>

Tb <sub>1</sub> (4) H <sub>2</sub> in air		(8) 2H <sub>2</sub> +O <sub>2</sub> +4N <sub>2</sub>		Tb <sub>1</sub> (7) 2H <sub>2</sub> +O <sub>2</sub> +4N <sub>2</sub>		Tb <sub>2.5</sub> (27) H <sub>2</sub> in O <sub>2</sub>	
% H <sub>2</sub>	cm/sec	Tb <sub>1</sub>		20°	350	% H <sub>2</sub>	cm/sec
20	200	Tb <sub>0.6</sub>	323	100°	430	59.9	574
25	280	Tb <sub>0.3</sub>	350			66.6	662
30*	340	Tb <sub>0.09</sub>	172			75.2	515
35	410	3H <sub>2</sub> +Cl <sub>2</sub>					
40	440	Tb <sub>1</sub>	315				
50	380	H <sub>2</sub> +3Cl <sub>2</sub>					
60	230	Tb <sub>1</sub>	600				

\* Not propagated in Tb<sub>0.09</sub> or less.

H<sub>2</sub> in air (<sup>16</sup>). A, in Tb<sub>0.9</sub>; B, in Tb<sub>1.15</sub>; C, in Tb<sub>2.5</sub>

% H <sub>2</sub>	A	% H <sub>2</sub>	B	% H <sub>2</sub>	C
11.80	No	17.30	150	6.10	No
17.30	125	25.15	260	6.19	10
23.65	200	33.90	383	6.31	12
30.45	320	37.15	400	20.15	260
36.55	390	40.10	410	29.70	405
40.10	420	43.10	420	36.30	490
43.10	420	46.80	400	40.50	480
46.80	400	51.55	360	44.55	460
50.55	353	57.15	270	49.15	385
57.00	280	59.45	175	61.60	145
62.00	155			71.39	50
63.50	No			71.51	*

\* Flame to open end only.

## CO

Tb <sub>2.5</sub> (23) CO in air, saturated with H <sub>2</sub> O at room temp. and P = 1 atm.		Effect of H <sub>2</sub> and H <sub>2</sub> O on flame speeds of CO — air mixtures ( <sup>34</sup> )				
% CO	cm/sec	t°	% CO	% H <sub>2</sub>	% H <sub>2</sub> O	cm/sec
		6	39.25	0.65	1.90	73.5
		28	38.00	0.65	3.70	103.5
		4	39.70	1.90	0.80	103.5
16.15	*	6	46.15	3.85	0.90	152.0
16.29	19.5	10	47.30	4.05	1.20	150.0
16.51	19.4	29	46.00	4.05	3.95	167.0
24.47	34.0	20	47.30	4.15	2.30	144.0
30.50	46.0	5	37.45	5.60	0.85	170.0
44.84	60.1	6	43.75	5.60	0.90	170.5
59.58	56.2	31	42.20	5.60	44.0	156.0
67.10	30.2	6	40.80	6.05	0.90	160.5
70.63	20.0	27	39.60	6.05	3.50	158.0
71.19	19.4	Tb <sub>1</sub> (7)				
71.31	†	2CO + O <sub>2</sub> , 220 cm/sec				

\* Flame tongue.

† Flame to 15 cm.

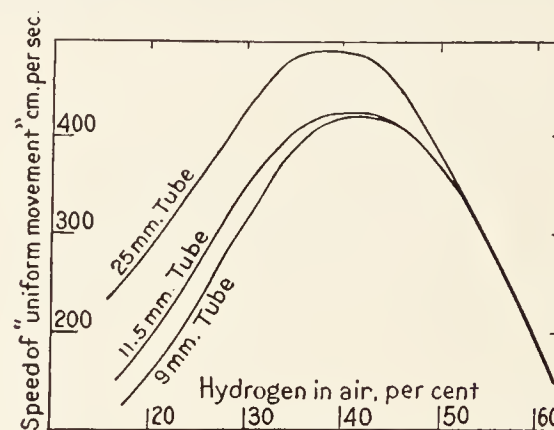


FIG. 5.—Influence of tube diameter on speed of "uniform movement" with mixtures of hydrogen and air (<sup>16</sup>).

Effect of H<sub>2</sub>O on flame-speed (<sup>33</sup>). Tb<sub>2.5</sub>. t° = temp. of saturation with H<sub>2</sub>O

t°	% H <sub>2</sub> O	cm/sec	t°	% H <sub>2</sub> O	cm/sec	t°	% H <sub>2</sub> O	cm/sec
2*	0.70	56	42*	8.00	118	27†	3.50	96
13*	1.45	76	4†	0.80	56	34†	5.20	107
27*	3.50	106	12†	1.35	68	39†	6.85	107
34*	5.20	120	20†	2.30	86			

\* = 45 % CO in air.

† = 40 % CO in air.

CH<sub>4</sub> Methane

CH <sub>4</sub> in air ( <sup>12</sup> ); cf. (3, 6, 7, 8). A in glass Tb <sub>2.65</sub> ; B in lead Tb <sub>2.64</sub> ; C in copper Tb <sub>2.3</sub> ; D in iron Tb <sub>2.72</sub>					CH <sub>4</sub> in air ( <sup>13</sup> ) Tb <sub>5</sub>	
% CH <sub>4</sub>	A	B	C	D	% CH <sub>4</sub>	cm/sec
5.99	21.7	19.4	18.3	21.2	5.4	36
6.83	33.4	32.5	32.7	34.1	6.8	55
7.6	45.6	43.5	42.4	43.8	8.8	100
7.95	48.6	48.2	45.2		9.45	110
8.94	63.66	58.7	59.4	63.3	10.6	109
10.0	69.8	65.0	63.2	67.3	11.5	84
10.98	61.1	53.9	54.1	57.5	13.0	42
11.3	53.3	45.4	47.7	50.6	14.3	36
11.74	36.9	35.2	34.5	36.1		



"Uniform-movement" velocities in tubes of small diameter (20).

D = internal diam. of tube in mm; % = % CH<sub>4</sub> in air

D \ %	7.6	8.0	8.25	8.4	8.5	9.0	9.5	9.95	10.15
3.6	0	0	0	0	0	0	0	0	0
4.5	0	0	(20)	(18)	(20)	(20)	(20)	(33)	0
5.6	(25)	(20)	(27)		36.3	38.4	40.8	41.2	40.8
7.2	(37)	(30)	(30)	(30)	38.0	40.5	46.8	46.3	44.5
8.1	(45)	(30)	(35)	36.5	39.3	42.4	47.7	47.4	46.7
9.0	(55)	32.6	34.8		40.4	44.4	48.9	48.0	47.9

D \ %	10.5	10.65	10.8	11.0	11.5	11.6	11.65	12.0
3.6	0	0	0	0	0	0	0	0
4.5	0	0	0	0	0	0	0	0
5.6	38.4	0	0	0	0	0	0	0
7.2	42.9	(60)	(53)	(43)	0	0	0	0
8.1	44.0	42.2	41.0	(45)	(50)			(60)
9.0	46.5	45.5		42.5	36.9	35.3	(69)	(60)

Figures in parentheses denote distance travelled before flame died out.

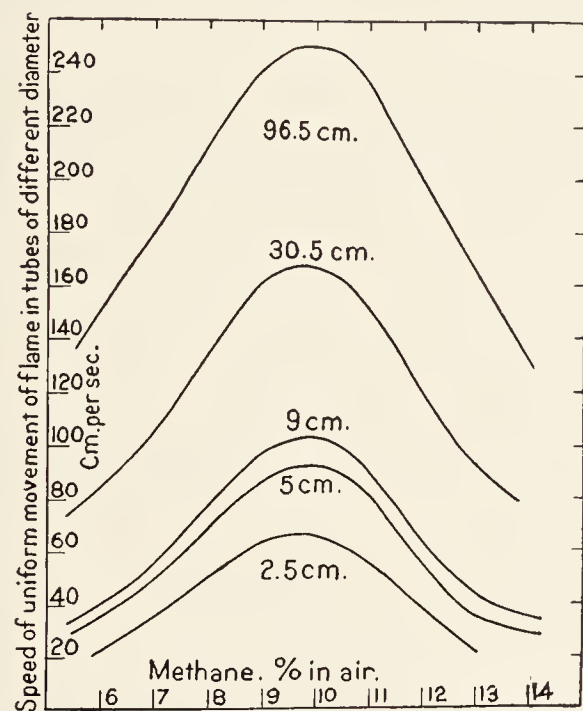


FIG. 6.—Influence of tube diameter on speed of "uniform movement" with mixtures of methane and air (19).

CH <sub>4</sub> in air, Tb <sub>2.5</sub> (23)		CH <sub>4</sub> in O <sub>2</sub> (27)	
% CH <sub>4</sub>	cm/sec	% CH <sub>4</sub>	cm/sec
5.71	*	5.59	†
5.80	23.3	5.72	20
6.95	35.0	10.52	266
7.82	47.4	15.53	722
9.12	64.4	21.63	2300
9.96	66.2	26.95	3991
10.32	65.5	33.00	5502
11.10	57.0	40.00	3020
12.25	35.0	45.61	488
13.09	22.0	53.36	82
13.35	19.1	57.67	29
13.42	†	59.50	‡

\* Flame to 15 cm.

† Flame to 5 cm.

‡ Flame to 30 cm.

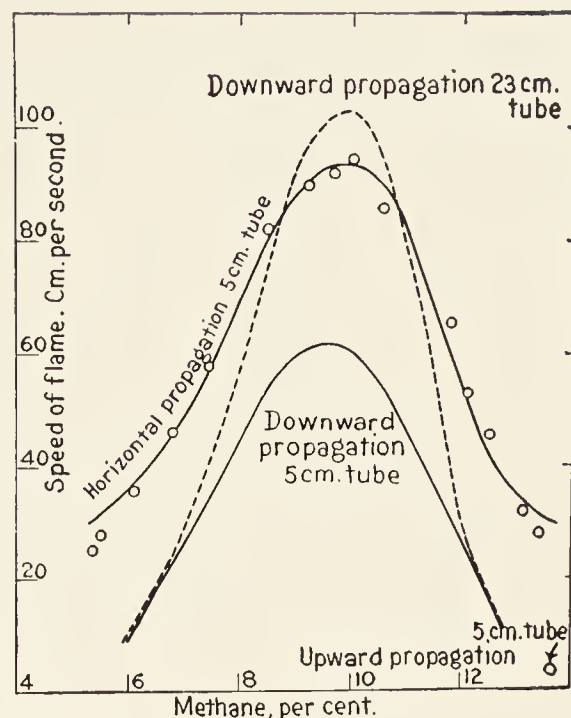


FIG. 7.—Influence of the direction of flame propagation on speed of "uniform movement" with mixtures of methane and air (20).

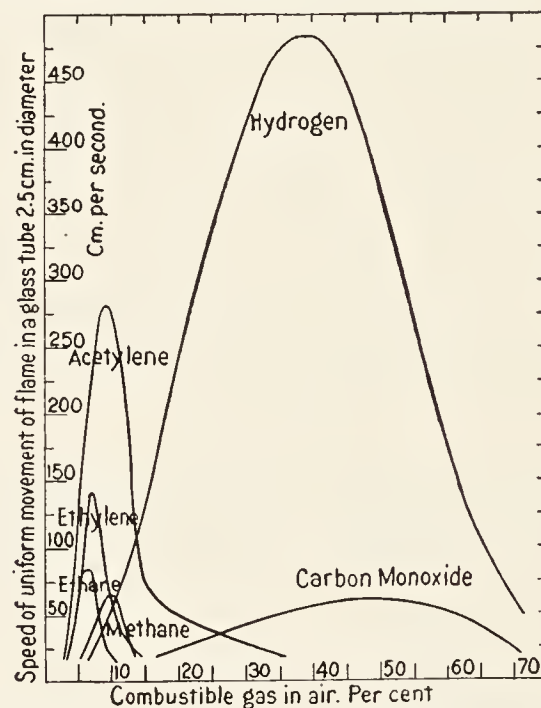


FIG. 8.—Comparison of the speeds of "uniform movement" of mixtures of various individual gases with air (29).

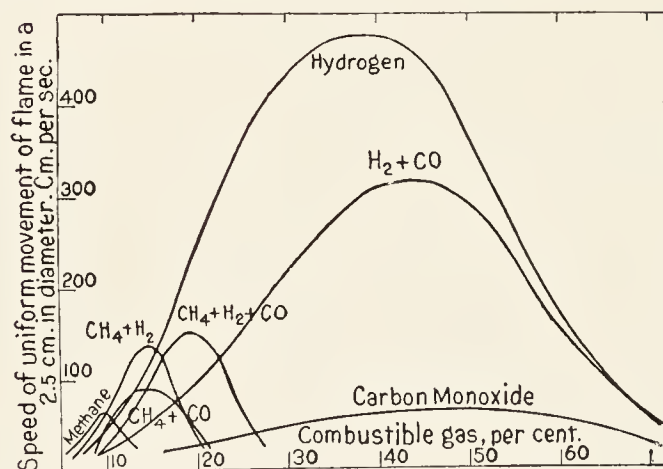


FIG. 9.—Speeds of "uniform movement" of mixtures of combustible gases with air (23).

C <sub>2</sub> H <sub>2</sub> Acetylene							
C <sub>2</sub> H <sub>2</sub> in air		C <sub>2</sub> H <sub>2</sub> in air		C <sub>2</sub> H <sub>2</sub> in air (22)			
Tb <sub>4</sub> (9)		Tb <sub>0.9</sub> (17)		% C <sub>2</sub> H <sub>2</sub>	Diam. of tube in mm		
% C <sub>2</sub> H <sub>2</sub>	cm/sec	% C <sub>2</sub> H <sub>2</sub>	cm/sec		12.5	25	50 90
2.9*	10	4	45	2.75			40
8.0	500	6	147	3.45	25	41	60
9.0-10.0	600	8	260	4.40			115
22.0	40	9	266	4.60	82	95	115
64*	5	10	264	6.10	158	172	205
		12	175	7.00			265
		14	114	8.15	258	270	303
		16	75	9.45			335
		18	50	10.35	260	278	304
		20	38	11.6	206	245	283
				11.85			285
				13.25	115	145	175 220
				16.00	60	68	72
				18.20			60 70

\* Limit.

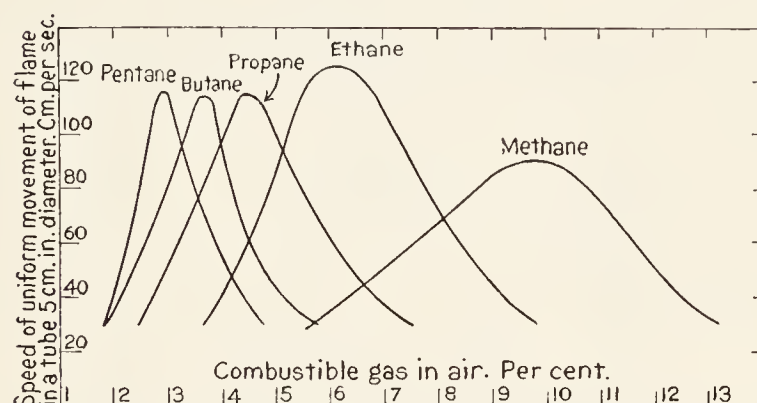


FIG. 10.—Speed of “uniform movement” of mixtures of the paraffin series with air (31).

C <sub>2</sub> H <sub>4</sub> Ethylene		C <sub>2</sub> H <sub>6</sub> Ethane		C <sub>3</sub> H <sub>8</sub> Propane		C <sub>4</sub> H <sub>10</sub> Butane	
In air (29)		In air (23)		In air (23)		In air (22)	
Tb <sub>2.5</sub> % C <sub>2</sub> H <sub>4</sub>	cm/sec	Tb <sub>2.5</sub> % C <sub>2</sub> H <sub>6</sub>	cm/sec	Tb <sub>2.5</sub> % C <sub>3</sub> H <sub>8</sub>	cm/sec	Tb <sub>2.5</sub> % C <sub>4</sub> H <sub>10</sub>	cm/sec
3.55	25.8	3.16	*	2.30	†	1.90	†
4.00	41.3	3.30	18.1	2.37	20.8	1.95	20.1
6.10	108.4	3.58	25.6	2.58	26.0	2.05	23.3
6.50	129.9	4.47	52.7	2.80	31.4	2.57	49.1
7.20	142.4	4.90	65.0	3.50	48.2	3.01	67.9
8.10	120.6	5.57	80.5	4.28	72.8	3.40	80.2
9.45	72.6	6.08	82.5	4.39	79.1	3.66	82.6
13.35	23.5	6.53	85.6	4.71	82.1	4.05	75.0
14.00	22.2	7.07	81.3	4.84	80.2	4.34	61.9
		7.70	60.4	5.14	66.0	4.88	43.4
		8.23	45.8	5.90	41.2	5.50	27.7
		9.00	27.7	6.58	30.2	6.27	22.0
		9.50	23.1	7.10	23.0	6.53	20.3
		10.09	20.8	7.30	20.3	6.60	
		10.60	19.7	7.35	§		
		10.71	†				

\* Flare only.

§ Flare to 15 cm.

† Flare to 4 cm.

|| Flare to open end only.

‡ Flare to 6 cm.

C <sub>5</sub> H <sub>12</sub> Pentane				C <sub>3</sub> H <sub>6</sub> O Acetone		CS <sub>2</sub> +3NO(7)	
In air (23). Tb <sub>2.5</sub>				In air (17)		Cf. (5, 8)	
% C <sub>5</sub> H <sub>12</sub>	cm/sec	% C <sub>5</sub> H <sub>12</sub>	cm/sec	Tb <sub>2.5</sub>			
1.52	*	3.85	48.0	% C <sub>3</sub> H <sub>6</sub> O	cm/sec		
1.61	20.2	4.00	44.0	2.70	55.0	Tb <sub>3</sub>	125
1.98	40.1	4.32	33.0	3.85	69.0	Tb <sub>2</sub>	124
2.35	60.2	4.56	28.7	5.05	93.8	Tb <sub>1</sub>	75
2.63	74.3	4.87	25.8	6.40	68.5	Tb <sub>0.4</sub>	
2.92	83.0	5.40	20.2	7.65	39.5		
3.00	82.1	5.50	†	8.20	30.5		
3.13	76.0						
3.35	65.9						
3.49	61.5						

\* Flame to 6 cm.

† Flame to open end only.

## LITERATURE

(For a key to the periodicals see end of volume)

- (1) Bunsen, 8, 131: 161; 67. (2) Mallard, 15, 7: 355; 75. (3) Fonseca Benevides, 407, 7: 166; 80. (4) Mallard and Le Chatelier, 34, 93: 145; 81. (5) Mallard and Le Chatelier, 34, 95: 599; 82. (6) Mallard, 185, 15: 268; 82. (7) Mallard and Le Chatelier, 51, 1: 173; 82. 27, 39: 369, 572; 83. (8) Mallard and Le Chatelier, 15, 4: 296; 83. (9) Le Chatelier, 34, 121: 1144; 95.
- (10) Bunte, 25, 31: 19; 98. (11) Sellars and Campbell, 54, 32: 730; 13. (12) Parker and Rhead, 4, 105: 2150; 14. (13) Wheeler, 4, 105: 2606; 14. (14) Morgan, 115, 99: 39; 15. 67, 26: 172; 14. (15) Parker, 4, 107: 328, 15. (16) Haward and Otagawa, 4, 109: 83; 16. (17) Wheeler and Whitaker, 4, 111: 267; 17. (18) Haward and Sastry, 4, 111: 841; 17. (19) Mason and Wheeler, 4, 111: 1044; 17.
- (20) Payman and Wheeler, 4, 113: 656; 18. (21) Payman and Wheeler, 4, 115: 36; 19. (22) Mason and Wheeler, 4, 115: 578; 19. (23) Payman, 4, 115: 1446, 1454; 19. (24) Morgan, 115, 108: 535; 19. (25) Nickolls, Underwriters Labs. Special Investigation No. 528; 19. (26) Mason and Wheeler, 4, 117: 36; 20. (27) Payman, 4, 117: 48; 20. (28) Mason and Wheeler, 4, 117: 1227; 20. (29) Chapman, 4, 119: 1677; 21.
- (30) Payman and Wheeler, 4, 121: 363; 22. (31) Mason, 4, 123: 210; 23. (32) Payman, 4, 123: 412; 23. (33) Payman and Wheeler, 4, 123: 1251; 23. (34) Ellis, 4, 123: 1435; 23. (35) Campbell and Ellis, 4, 125: 1957; 24. (36) Ellis and Stubbs, 4, 125: 1960; 24. (37) Ellis and Robinson, 4, 127: 760; 25. (38) Ellis and Wheeler, 4, 127: 764; 25. (39) Gouy, 6, 18: 1; 79. (40) Bunte, 25, 31: 19; 98. (41) Hofsass, 397, 62: 541; 19. (42) Payman and Wheeler, 83, preprint, 1926.

## THEORETICAL

- (43) Vicaire, 6, 19: 118; 70. (44) Mallard and Le Chatelier, 15, 4: 296; 83. (45) Jouguet, 34, 156: 872; 13. (46) Nusselt, 98, 59: 872; 15. (47) Jouguet and Crussard, 34, 168: 820; 19.

## DETONATION

The phenomenon of detonation, or “l’onde explosive” as it was originally known, in gaseous explosions was discovered by Berthelot and Vieille and by Mallard and Le Chatelier in the year 1881. It is set up when a sufficiently explosive mixture is ignited by means of a detonator (such as fulminate) or under circumstances such that the burning gases are exposed to the repeated effects of reflected compression waves. In the last named circumstance the initial uniform slow velocity is rapidly accelerated up to the point of detonation.

When once established its velocity is constant and within wide limits unaffected by the material and diameter of the tube employed, being solely dependent on the nature of the explosive mixture and on its temperature and pressure.

In the explosion wave the explosive mixture is fired adiabatically by compression so that the chemical reaction is more intense and of much shorter duration than in the case of normal combustion. In addition the pressure in the wave is much greater than in ordinary explosions, this being the cause of its shattering effect.

## Abbreviations

Values not otherwise designated are detonation velocities in meters per second.

Composition of gas mixtures when given in percentages are in volume %.



$2\text{CO} + \text{O}_2$ ; influence of  $\text{H}_2\text{O}$  vapor (8);  $t^\circ$  = saturation temp.CH<sub>4</sub> Methane

**C<sub>2</sub>H<sub>2</sub> Acetylene**

$t^\circ$	% H <sub>2</sub> O	$P_{\text{mm}}$	m/sec	$t^\circ$	% H <sub>2</sub> O	$P_{\text{mm}}$	m/sec
	Well-dried		1264	35	5.6	760	1738
	Dry		1305	35	5.6	1100	1782
10	1.2		1676	45	9.5	400	1570
20	2.3	400	1576	45	9.5	760	1693
20	2.3	760	1703	45	9.5	1100	1742
20	2.3	1100	1737	55	15.6		1666
28	3.7		1713	65	24.9		1526
35	5.6	400	1616	75	38.4		1266

(8)			In O <sub>2</sub> (24)		(3)	
CH <sub>4</sub> + 2O <sub>2</sub>		CH <sub>4</sub> + 2O <sub>2</sub> 2146	% CH <sub>4</sub>		CH <sub>4</sub> + 2O <sub>2</sub> 2287	
<i>P</i> <sub>mm</sub>	m/sec	CH <sub>4</sub> + 4O <sub>2</sub> 1963	11.1	1678	CH <sub>4</sub> + 2N <sub>2</sub>	} 1858
500	2280	CH <sub>4</sub> + 1½O <sub>2</sub>	20.0	1980	+ 4O <sub>2</sub>	
760	2322	+ ½N <sub>2</sub>	25.0	2146	CH <sub>4</sub> + 4N <sub>2</sub>	} 1151
1000	2319	CH <sub>4</sub> + 1½O <sub>2</sub>	33.3	2337	+ 2O <sub>2</sub>	
CH <sub>4</sub> + 1½O <sub>2</sub>		+ 1½N <sub>2</sub>	40.0	2465	CH <sub>4</sub> + 7.52 N <sub>2</sub> + 2O <sub>2</sub>	
500	2418	CH <sub>4</sub> + 1½O <sub>2</sub>	50.0	2513	gives no detonation.	
760	2470	+ 2½N <sub>2</sub>	53.3	2388		
1000	2488					

--	--

(13)				(8)	
2C <sub>2</sub> H <sub>2</sub> + O <sub>2</sub>	2160	C <sub>2</sub> H <sub>2</sub> + 6O <sub>2</sub>	1950	C <sub>2</sub> H <sub>2</sub> + 2½O <sub>2</sub>	2391
1½C <sub>2</sub> H <sub>2</sub> + O <sub>2</sub>	2510	C <sub>2</sub> H <sub>2</sub> + 10O <sub>2</sub>	1850	C <sub>2</sub> H <sub>2</sub> + 1½O <sub>2</sub>	2716
C <sub>2</sub> H <sub>2</sub> + O <sub>2</sub>	2920	C <sub>2</sub> H <sub>2</sub> + 2N <sub>2</sub> O	2580	C <sub>2</sub> H <sub>2</sub> + 1½O <sub>2</sub> + N <sub>2</sub>	2414
C <sub>2</sub> H <sub>2</sub> + 3O <sub>2</sub>	2220	C <sub>2</sub> H <sub>2</sub> + 6N <sub>2</sub> O	2400	C <sub>2</sub> H <sub>2</sub> + O <sub>2</sub>	2961 (16)
C <sub>2</sub> H <sub>2</sub> + 4O <sub>2</sub>	2190	C <sub>2</sub> H <sub>2</sub> + 2NO	2850	C <sub>2</sub> H <sub>2</sub> + 2½O <sub>2</sub>	2482 (3)
		C <sub>2</sub> H <sub>2</sub> + 6NO	2800		

98% C<sub>2</sub>H<sub>2</sub> (**12**). Determinations made in tube 1 m long × 3.5 mm diam. Since C<sub>2</sub>H<sub>2</sub> is an endothermic compound, it can be detonated under pressure.

$P$  = initial detonating pressure in kg/cm<sup>2</sup>.

$P$ .....	5	10	12	15	20	30
Speed.....	1050	1100	1280	1320	1500	1600

**C<sub>2</sub>H<sub>4</sub> Ethylene (8)**

$\text{C}_2\text{H}_4 + 2\text{O}_2^*$	2581	$\text{C}_2\text{H}_4 + 6\text{O}_2$	2118	$\text{C}_2\text{H}_4 + 2\text{O}_2$	} 2211
$\text{C}_2\text{H}_4 + 2\text{O}_2^\dagger$	2538	$\text{C}_2\text{H}_4 + 8\text{O}_2$	1980	+ $2\text{N}_2$	
$\text{C}_2\text{H}_4 + 3\text{O}_2$	2364	$\text{C}_2\text{H}_4 + 10\text{O}_2$	1856	$\text{C}_2\text{H}_4 + 2\text{O}_2$	} 2024
$\text{C}_2\text{H}_4 + 4\text{O}_2$	2247	$\text{C}_2\text{H}_4 + 2\text{O}_2 + \text{N}_2$	2413	+ $4\text{N}_2$	
(3)				$\text{C}_2\text{H}_4 + 2\text{O}_2$	} 1878
$\text{C}_2\text{H}_4 + 3\text{O}_2$	2209			+ $6\text{N}_2$	
				$\text{C}_2\text{H}_4 + 2\text{O}_2$	} 1734
				+ $8\text{N}_2$	

\*  $10^\circ$ .  
†  $100^\circ$ .

**C<sub>2</sub>H<sub>6</sub> Ethane**

$$\text{C}_2\text{H}_6 + 3\frac{1}{2}\text{O}_2, 2363 \text{ (3)}$$

**C<sub>2</sub>N<sub>2</sub> Cyanogen**

**C<sub>2</sub>N<sub>2</sub> Cyanogen**

(3)		(8)			(22)	
$C_2N_2 + 4N_2O$	2035	$P_{mm}$	$C_2N_2$	$C_2N_2 + 2O_2,$	$C_2N_2 + O_2$	
$C_2N_2 + 2O_2$	2043		$+ O_2$	2321	$+ 2N_2$	
$C_2N_2 + 2N_2$	1203	500	2536	$C_2N_2 + 3O_2,$	Diam.	m/sec
$+ 2O_2$		760	2677	2110	of tube	
$C_2N_2 + 4N_2$	*	1000	2671	$C_2N_2 + O_2$	6 mm	2161
$+ 2O_2$		$t^\circ$		$+ N_2, 2398$	9 mm	2230
$P_{mm}$	$C_2N_2 + 2O_2$	10	2728	$C_2N_2 + O_2$	12.7 mm	2230
388	2171	100	2711	$+ N_2, 2165$		
758	2195					
878	2052					

‡ Undulatory.

\* Detonation not propagated.

## MIXTURES OF COMBUSTIBLE GASES

(23)						(8)	
2(xH <sub>2</sub> + yCO) + O <sub>2</sub>			4(xH <sub>2</sub> + yCO) + O <sub>2</sub>			2H <sub>2</sub> + O <sub>2</sub>	2455
x	y	m/sec	x	y	m/sec	+ 2CO	
0.75	99.25	1754	1	99	1747	2H <sub>2</sub> + O <sub>2</sub>	2080
1.5	98.5	1758	2	98	1755	+ 6CO	
7.5	92.5	1796	5	95	1776	H <sub>2</sub> + O <sub>2</sub>	2143
15	85	1858	25	75	1952	+ 2CO	
37.5	62.5	2020	50	50	2212	(3)	
50	50	2130	75	25	2614	H <sub>2</sub> + O <sub>2</sub>	2008
75	25	2391	85	15	2819	+ CO	
85	15	2507	92.5	7.5	3015	3H <sub>2</sub> + 2½O <sub>2</sub>	2170
92.5	7.5	2643	100	0	3284	+ 2CO	
100	0	2810				H <sub>2</sub> + C <sub>2</sub> H <sub>4</sub>	2417
H <sub>2</sub> + CH <sub>4</sub> (24). M = % mixture in O <sub>2</sub>						+ 3½O <sub>2</sub>	
H <sub>2</sub> + CH <sub>4</sub>		2H <sub>2</sub> + CH <sub>4</sub>		H <sub>2</sub> + 2CH <sub>4</sub>		2H <sub>2</sub> + C <sub>2</sub> H <sub>4</sub>	2579
M	m/sec	M	m/sec	M	m/sec	+ 4O <sub>2</sub>	
13.8	1532	14.3	1449	14.3	1728	H <sub>2</sub> + C <sub>2</sub> H <sub>6</sub>	2250
21.0	1875	15.8	1582	25.0	2050	+ 4O <sub>2</sub>	
44.4	2464	16.7	1666	40.0	2444		
50.0	2561	20.0	1764	46.1	2546		
57.1	2697	33.3	2094	50.0	2605		
66.7	2604	50.0	2474	54.5	2679		
		54.5	2572	60.0	2600		
		66.7	2782				

## LIMITING DILUTIONS OF EXPLOSIVE MIXTURES FOR THE INITIATION OF DETONATION

Detonation cannot be propagated in mixtures diluted beyond the limits given

	Limits	Speed	Lit.
$H_2$ and air.....	Lower 23.3% $H_2$ Between 21.7% $H_2$	1205 *	(3)
CO.....	$4CO + 2N_2 + O_2$ $2CO + N_2 + O_2$	* *	(3) (3)
$CH_4$ Methane.....	$CH_4 + O_2$ Lower 11.1% $CH_4$ Upper 53.3% $CH_4$	1678 2388	(24)
	$CH_4 + 4N_2 + 2O_2$ $CH_4 + 7.5N_2 + 2O_2$ 9.5% $CH_4$ in air	1151 * *	(3) (3) (3)
$C_2H_2$ Acetylene.....	$C_2H_2 + 10O_2$ $C_2H_2 + 6NO$	1850 2800	(13) (13)
$C_2N_2$ Cyanogen.....	$C_2N_2 + 2N_2 + 2O_2$ $C_2N_2 + 4N_2 + 2O_2$ $C_2N_2 + 4N_2O$ $C_2N_2 + 4NO$	1203 * 2035† *	(3) (3) (3) (3)

\* Detonation not propagated.

† Sometimes propagated.

Mean flame velocity before a uniform detonation speed ensues (3).  $2H_2 + O_2$ , in rubber tube 5 mm diam.;  $D$  = distance from initiating explosive in m;  $S$  = time in sec;  $V$  = mean vel. from origin in m/sec;  $V_{int.}$  = mean vel. in each interval.

$D$	$S$	$V$	$V_{int.}$
0.020	0.000275	72.72	72.7
0.050	0.000342	146.2	448.0
0.500	0.000541	924.4	2261
5.250	0.002108	2491.0	3031
20.190	0.007620	2649.0	2710
40.430	0.015100	2679.0	2706

Distance in inches from spark at which detonation occurs =  $D_0$  for spark at end of tube and  $D_3$  for spark 3 in. from end (16).

Mixture	$D_0$	$D_3$
$2H_2 + O_2$	48	12
$2H_2 + 2\frac{1}{2}O_2$		48
$6H_2 + O_2$		192
$C_2N_2 + O_2$	$8\frac{1}{2}$	4
$C_2N_2 + 2O_2$	12	10
$2C_2H_2 + 3O_2$	$4\frac{1}{2}$	$2\frac{1}{2}$
$C_2H_4 + 2O_2$	9	5

Distance before detonation wave is established =  $D$  cm (13).  
Glass tube, 10 mm diam. Spark at end of tube

Mixture	$D$
$2C_2H_2 + O_2$	100
$C_2H_2 + O_2$	5
$C_2H_2 + 6O_2$	15
$C_2H_2 + 10O_2$	80
$C_2H_2 + 2NO$	20
$C_2H_2 + 6NO$	50
$C_2H_2 + 2N_2O$	100
$C_2H_2 + 6N_2O$	10

Influence of tube diameter on the distance from the firing source at which detonation occurs (25). Mixture =  $CS_2 + 3O_2$ . Spark at end of tube.  $D_{cm}$  = cm travelled by flame before detonation.

Tube diam., mm	$D_{cm}$
6.5-7	48
10	50
24-25	58
34-35	84
43-44	103
53-54	131

Distance required for the re-establishment of detonation waves after they are damped out by passing from one tube to another of larger diameter (26). Diam. of first tube = 7 mm. Distance in cm travelled by flame in second tube prior to detonation =  $D$ .

Diam. mm second tube.....	13	16	23-24	33-34	44-45
$D (CS_2 + 3O_2)$ .....	8	10	15	50	100
$D (2H_2 + O_2)$ .....			3	62	

## WAVE VELOCITIES (14)

	$C_2H_2 + O_2$	$C_2H_2 + 2NO$	$2CO + O_2$
L'onde explosive (détonation wave).....	2990	2850	1900
L'onde rétrograde (retonation wave)*.....	2300	1140	
L'onde réfléchie (reflexion wave)†.....	2250	1350	1000
L'onde prolongée (collision wave)‡.....	2050		

\* A "retonation" wave is thrown back into the burnt gases when the detonation wave is set up.

† The wave reflected through the burnt gases after a detonation wave has reached the walls of the vessel in which the explosion occurs.

‡ Collision waves occur when two detonation waves meet.

REFLECTED WAVES IN A  $C_2H_2 + O_2$  MIXTURE

Initial speed.....	2300	After first crossing.....	1080
After reflection.....	1350	After second crossing...	980



## RATIO OF WAVE VELOCITIES (16)

Mixture	Detonation wave velocity	Reflection wave velocity	Ratio of velocities
2H <sub>2</sub> + O <sub>2</sub> .....	2820	1538	1.83
H <sub>2</sub> + N <sub>2</sub> O.....	2305	1383	1.67
2CO + O <sub>2</sub> .....	1676	1078	1.56
C <sub>2</sub> N <sub>2</sub> + O <sub>2</sub> .....	2728	1230	2.22
C <sub>2</sub> N <sub>2</sub> + 2O <sub>2</sub> .....	2321	1129	2.06
2C <sub>2</sub> N <sub>2</sub> + 5O <sub>2</sub> .....	2391	1133	2.11

Two equations of importance have been deduced whereby velocities of detonation agreeing closely with experimental values may be calculated (34, 35).

$$V^2 = \frac{2RJ}{\mu C_v} [(m-n)C_p + mC_v] C_p T_o + (C_p + C_v)h \text{ where}$$

$V$  Velocity of wave.

$R$  Gas constant.

$J$  Dynamical equivalent of heat ( $42 \times 10^6$  ergs).

$\mu$  Gram equivalents of the mixture exploded.

$n$  and  $m$  Number of molecules before and after the chemical change in the wave.

$C_p$  and  $C_v$  Mean specific heats of the products at constant pressure and volume, respectively.

$h$  Total heat generated in the wave.

$T_o$  Initial temperature (abs.) of the mixture exploded.

$$\left(\frac{dP}{dt}\right)^2 = \mu^2 \frac{Rk_2 T_2}{M} \left(1 + \frac{k_2 R}{MC_2}\right), \text{ where}$$

$\left(\frac{dP}{dt}\right)$  Velocity of the wave.

$R$  Gas constant.

$M$  Molecular mass of the gas taken.

$T_2$  Temperature of the flame.

$\mu$   $\frac{d_2}{d_1}$  (ratio of the final and initial densities).

$C_2$  Mean specific heat at constant volume of the explosion products.

$k_2$  Number of molecules in the explosion products.

## LITERATURE

(For a key to the periodicals see end of volume)

## EXPERIMENTAL

- (1) Berthelot, 34, 93: 18; 81. (2) Mallard and Le Chatelier, 34, 93: 145; 81. (3) Berthelot and Vieille, 34, 94: 101; 82. 95: 151, 199; 82. 6, 28: 289; 83. 27, 40: 353; 83. (4) von Oettingen and von Gernet, 8, 33: 556; 88. (5) Dixon and Smith, 398, 2: 2; 89. (6) Dixon and Harker, 398, 3: 118; 90. (7) Lean and Bone, 133, 1892: 673. (8) Dixon, 62, 184: 97; 93. (9) Dixon and Cain, 398, 8: 180; 94. (10) Dixon, Strange and Graham, 4, 69: 759; 96. (11) Dixon and Harker, 4, 69: 789; 96. (12) Berthelot and Le Chatelier, 34, 129: 427; 99. (13) Le Chatelier, 6, 20: 15; 00. 34, 130: 1755; 00. (14) Le Chatelier, 34, 131: 30; 00. (15) Jones and Bower, 398, 42: No. 7; 98. (16) Dixon *et al.*, 62, 200: 345; 03. (17) Dixon and Bradshaw, 5, 79: 234; 07. (18) Bradshaw, 5, 79: 236; 07. (19) Dixon, 4, 99: 588; 11. (20) Dixon, Campbell and Slater, 5, 90: 506; 14. (21) Butcher, 2, 15: 228; 20. (22) Campbell, 4, 121: 2483; 22. (23) Dixon and Walls, 4, 123: 1025; 23. (24) Payman and Walls, 4, 123: 420; 23. (25) Laffitte, 34, 176: 1392; 23. (26) Laffitte, 34, 177: 178; 23. (27) Evreinoff, *Journal des Mines* (Russie), No. 2; 23. (28) Audibert, 34, 178: 1275; 24. (29) Laffitte, 34, 179: 1394; 24. (30) Wendlandt, 7, 110: 637; 24. (31) Malinowski, 42, 21: 468; 24. (32) Wendlandt, 7, 116: 227; 25. (32a) Laffitte, 16, 4: 587; 25.

## THEORETICAL

- (33) Berthelot, 34, 94: 149; 82. 96: 672; 83. (34) Chapman, 3, 47: 90; 89. (35) Jouguet, 34, 134: 1418; 02. 135: 778; 02. 138: 1685; 04. 139: 121. 786; 04. 140: 711; 05. 142: 831, 1034; 06. 408, 1: 347; 05. 2: 5; 06. (36) Zemlin, 34, 141: 710; 05. (37) Jouguet, 34, 144: 415; 07. (38) Crussard, 34, 144: 417; 07. (39) Crussard and Jouguet, 34, 144: 560; 07. (40) Jouguet, 34, 144: 632; 07. (41) Crussard, 401, 6: 297; 07. (42) Jouguet, 34, 146: 915; 08. (43) Jouguet and Crussard, 34, 146: 954; 08. (44) Jouguet, 34, 150: 91; 10. (45) Crussard, 34, 156: 447, 611; 13. (46) Jouguet, 34, 156: 872, 1058; 13. (47) Crussard, 34, 158: 125; 14. (48)

Jouguet and Crussard, 34, 168: 820; 19. (49) Crussard, 402, 12: 243, 295; 20. (50) Jouguet, 34, 181: 546; 25. (51) Vieille, 315, 10: 177; 89. 34, 131: 413; 00. (52) Jouguet, 34, 181: 658; 25. (53) Payman and Robinson, Safety in Mines and Research Board, Report No. 18; 26.

## EXPLOSIONS IN CLOSED VESSELS

Much of the experimental determination of explosion times and pressures using gaseous mixtures has been carried out with coal gas—air mixtures. Owing to the variable composition and heat of combustion of the samples of coal gas so employed, it has not been found possible to tabulate such data except in so far as they may have a general bearing on the subject of gaseous explosions—and more particularly where data relative to the simpler combustible gases are lacking.

All maximum pressures have been expressed as a ratio,  $\frac{\text{maximum pressure}}{\text{initial pressure}}$ , thus giving a better basis of comparison.

In most cases the published figures for initial pressures refer to room temperatures. Where this has been found to be otherwise, the initial pressures have been adjusted to correspond to a temperature of 15°C, and a corresponding correction applied to maximum pressures.

No attempt has been made to tabulate investigators' estimates of their explosion temperatures because (a) an arbitrary correction must necessarily be applied for cooling loss during the explosion period—this being dependent on the explosion vessel employed and (b) allowances must be made for dissociation. An approximate value of the temperature attained may be calculated from the formula

$$T_{(\text{max.}) \text{ abs.}} = \frac{P_{\text{max.}}}{P_{\text{init.}}} \times T_{(\text{init.}) \text{ abs.}} \times \frac{m}{n}$$

where  $m/n$  represents the molecular change.

Few direct determinations of explosion temperatures have been possible owing to the very high temperatures developed.

In comparing explosion times, consideration must be given to the dimensions of the explosion vessels concerned—on which they are solely dependent.

In the following tables all results may be considered to refer to explosions of gaseous mixtures at atmospheric pressure and temperature unless specially stated otherwise.

## Abbreviations

$\frac{P_{\text{max.}}}{P_{\text{init.}}}$	Ratio of maximum pressure developed to initial pressure.
$P_{\text{init.}}$	Initial pressure in atmospheres.
$T_{\text{init.}}$	Initial temperature in °C.
$V_x$	Vessel whose capacity is $x \text{ cm}^3$ , unless otherwise stated.
Cyl.	Cylindrical.
Con.	Conical.
Sphere	Spherical.
Exper. condn.	Experimental conditions.
Milli-sec	Time in milli-seconds to attain maximum pressure.

H<sub>2</sub>

Mixture	$\frac{P_{\text{max.}}}{P_{\text{init.}}}$	Milli-sec	Exper. condn.	Lit.
2H <sub>2</sub>				
+O <sub>2</sub>	9.5	10	Cyl., $V_{18}$	(2)
+O <sub>2</sub> + 4N <sub>2</sub>	6.5		Cyl., $V^*$	(6)
+O <sub>2</sub>	9.25		Cyl., $V_{4000}$	(9)
+O <sub>2</sub> + 2H <sub>2</sub>	8.34			
+O <sub>2</sub> + 4H <sub>2</sub>	7.58			
+O <sub>2</sub> + 6H <sub>2</sub>	6.67			
+O <sub>2</sub> + 2O <sub>2</sub>	8.2			
+O <sub>2</sub> + 6O <sub>2</sub>	6.4			
+O <sub>2</sub> + N <sub>2</sub>	8.65			
+O <sub>2</sub> + 2N <sub>2</sub>	8.26			
+O <sub>2</sub> + 4N <sub>2</sub>	7.5			
+O <sub>2</sub> + 6N <sub>2</sub>	6.5			

$H_2$ —(Continued)

Mixture	$P_{max.}$ $P_{init.}$	Milli- sec	Exper. condn.	Lit.
+2N <sub>2</sub> O	12.85		Cyl., $V_{4000}$	(9)
+2N <sub>2</sub> O + 2N <sub>2</sub>	10.47			
+O <sub>2</sub>	7.41	1.04	Cyl., $V_{300}$	(11, 15)
+O <sub>2</sub>	9.69	2.14	Cyl., $V_{4000}$	(11, 15)
+O <sub>2</sub> + $\frac{1}{2}H_2$		2.27		
+O <sub>2</sub> + $\frac{1}{3}H_2$		2.53	Cyl., $V_{4000}$	(11, 15)
+O <sub>2</sub> + $\frac{1}{4}H_2$		2.41		
+O <sub>2</sub> + H <sub>2</sub>		2.82		
+O <sub>2</sub> + 2H <sub>2</sub>		1.67	Cyl., $V_{300}$	(11, 15)
+O <sub>2</sub> + 2H <sub>2</sub>		4.22		
+O <sub>2</sub> + 3H <sub>2</sub>		5.95		
+O <sub>2</sub> + 4H <sub>2</sub>		9.67		
+O <sub>2</sub> + 2O <sub>2</sub>		8.16		
+O <sub>2</sub> + 6O <sub>2</sub>		16.04	Cyl., $V_{4000}$	(11, 15)
+O <sub>2</sub> + N <sub>2</sub>		2.86		
+O <sub>2</sub> + $\frac{1}{2}N_2$		3.55		
+O <sub>2</sub> + 2N <sub>2</sub>	8.63	6.87		
+O <sub>2</sub> + 2N <sub>2</sub>	7.60	2.67	Cyl., $V_{300}$	(11, 15)
+O <sub>2</sub> + 4N <sub>2</sub>	7.55	11.98	Cyl., $V_{4000}$	(11, 15)
+O <sub>2</sub> + 4N <sub>2</sub>	7.34		Cyl., $V_{300}$	(11, 15)
+O <sub>2</sub> + 6N <sub>2</sub>	6.64	24.45	Cyl., $V_{4000}$	(11, 15)
+O <sub>2</sub> + 6N <sub>2</sub>	6.12		Cyl., $V_{300}$	(11, 15)
+O <sub>2</sub> + 8N <sub>2</sub>		36.35	Cyl., $V_{300}$	(11, 15)
+O <sub>2</sub>	8.48			
+O <sub>2</sub> + $\frac{1}{2}O_2$	8.37			
+O <sub>2</sub> + 3O <sub>2</sub>	7.94		Cyl., $V_{4000}$	(13) Cf. (5, 7)
+O <sub>2</sub> + 6O <sub>2</sub>	7.0			
+O <sub>2</sub> + 3H <sub>2</sub>	8.02			
+O <sub>2</sub> + 4N <sub>2</sub>	6.8	9.5	Con., $V_{115}$ in. <sup>3</sup> , ignit. at vertex	(68)
+O <sub>2</sub> + 4N <sub>2</sub>	7.54†	8.4	1.15	(75)
+O <sub>2</sub> + 4N <sub>2</sub>	7.96†	6.9	3.0	
+O <sub>2</sub> + 4N <sub>2</sub>	8.14†	6.1	5.5	
+O <sub>2</sub> + 4N <sub>2</sub>	7.98	5.5		
+O <sub>2</sub> + 2N <sub>2</sub>	8.28	2.2		
+O <sub>2</sub> + 4H <sub>2</sub>	8.1	1.0		
+O <sub>2</sub> + 2H <sub>2</sub>	9.13	1.0	$T_{init.} = 15^\circ C$	
+O <sub>2</sub>	9.3	0.7	$P_{init.} = 2$ atm.	(75)
+O <sub>2</sub> + 4O <sub>2</sub>	7.7	2.9	Cyl., $V^*$	
+O <sub>2</sub> + 2O <sub>2</sub>	8.8	1.5		
+O <sub>2</sub> + 4CO <sub>2</sub>	5.65	25.5		
+O <sub>2</sub> + 2CO <sub>2</sub>	7.10	4.6		
+O <sub>2</sub> + 4N <sub>2</sub>	7.7	5 or 3		
	7.8	less, 10		
	8.0	de- 25		
	8.1	creas- 50		
	8.33	ing 75	Pinit. $V_{240}$	(79)
	8.50	at 100	$T_{init.} = 17^\circ C$	
	8.64	high- 125		
	8.67	er 150		
	8.80	Pinit. 175		
	7.7			
+O <sub>2</sub> + 4N <sub>2</sub>	7.84			
	8.05	Same as above except $P_{max.}/P_{init.}$ has been corrected: $P_{max.}$ for cooling losses during combustion period; $P_{init.}$ for deviation from Boyle's law.		
	8.16			
	8.43			(79)
	8.63			
	8.79			
H <sub>2</sub>	8.82			
	8.98			
+N <sub>2</sub> O		2.06	Cyl., $V_{300}$	(11, 15)
+Cl <sub>2</sub> + 3.6H <sub>2</sub>	6.88		Cyl., $V_{4000}$	(13) cf. (5, 7)
% H <sub>2</sub> in air	Values calculated from published temp. estimates			
25.4	7.23		Cyl., $V_{30}$ cm	
15.3	5.03		diam., 30 cm deep	(61)
10.0	4.03			

## CO

2CO				
+O <sub>2</sub>	10.1		Cyl., $V_{18}$	(2)
+O <sub>2</sub> + 4N <sub>2</sub>	7.3		Cyl., $V_{18}$	(2)

\* Diam. 7 in., depth 8 in.

† Calculated to  $T_{init.} = 15^\circ$ .

## CO.—(Continued)

Mixture	$P_{max.}$ $P_{init.}$	Milli- sec	Exper. condn.	Lit.
+O <sub>2</sub>	9.56			
+O <sub>2</sub> + N <sub>2</sub>	8.82		Cyl., $V_{4000}$	(9)
+O <sub>2</sub> + 2N <sub>2</sub>	8.28			
+O <sub>2</sub> + 5N <sub>2</sub>	6.66			
+O <sub>2</sub>	9.42			
+O <sub>2</sub> + $\frac{1}{2}CO_2$	7.50			
+O <sub>2</sub> + 3CO <sub>2</sub>	6.50			
+O <sub>2</sub> + $\frac{1}{2}CO$	4.8			
+O <sub>2</sub> + $\frac{1}{2}CO$	8.33		Cyl., $V_{4000}$	(13) cf. (5, 7)
+O <sub>2</sub> + 6CO	7.01			
+O <sub>2</sub> + $\frac{1}{2}O_2$	8.52			
+O <sub>2</sub> + 6O <sub>2</sub>	6.40			
+O <sub>2</sub> + $3\frac{1}{2}N_2$	7.24			
+O <sub>2</sub> + $7\frac{1}{2}N_2$	5.98			
+O <sub>2</sub>	9.29	12.86	Cyl., $V_{300}$	(11, 15)
+O <sub>2</sub>	9.93	15.51	Cyl., $V_{4000}$	(11, 15)
+O <sub>2</sub> + N <sub>2</sub>		17.78	Cyl., $V_{300}$	(11, 15)
+O <sub>2</sub> + 2N <sub>2</sub>		26.49	Cyl., $V_{300}$	(11, 15)
+O <sub>2</sub> + CO <sub>2</sub>		27.18	Cyl., $V_{300}$	(11, 15)
+O <sub>2</sub> + 2CO <sub>2</sub>		35.80	Cyl., $V_{300}$	(11, 15)
+O <sub>2</sub>	10.0	12.5	4.3	(73)
+O <sub>2</sub>	11.5	5.0	21.4	
+O <sub>2</sub>	12.1	5.0	50.0	
+O <sub>2</sub> + 2A	10.6	10		
+O <sub>2</sub> + 2O <sub>2</sub>	10.3	5	Sphere, $V_{240}$	
+O <sub>2</sub> + 2CO	10.01	5	$P_{init.} = 35.7$	(69)
+O <sub>2</sub> + 2N <sub>2</sub>	9.55	40	$T_{init.} = 17^\circ C$	
+O <sub>2</sub> + 4A	10.20	25		
+O <sub>2</sub> + 4O <sub>2</sub>	9.20	5	Sphere, $V_{240}$	
+O <sub>2</sub> + 4CO	9.00	10	$P_{init.} = 50$	(69)
+O <sub>2</sub> + 4N <sub>2</sub>	8.30	190	$T_{init.} = 17^\circ C$	
+O <sub>2</sub> + 6A	9.7	140	Sphere, $V_{240}$	
+O <sub>2</sub> + 6CO	7.9	130	$P_{init.} = 64.3$	(69)
+O <sub>2</sub> + 6N <sub>2</sub>	6.4	1100	$T_{init.} = 17^\circ C$	
+O <sub>2</sub> + 4A	8.5	35	3.0	
	8.9	50	10.0	
	10.2	25	50.0	Sphere, $V_{240}$
	10.53	15	75.0	Pinit.
	10.63	10	100.0	$T_{init.} = 17^\circ C$
	11.2	10	125.0	
	11.66	10	150.0	
	8.65			
	9.1			
	10.1			
+O <sub>2</sub> + 4O <sub>2</sub>	10.3			(79)
	10.33			
	10.84			
	11.4			
	7.6	60	3.0	
	7.7	45	10.0	Sphere, $V_{240}$
	8.6	10	25.0	Pinit.
	9.2	5	50.0	$T_{init.} = 17^\circ C$
	10.1	5	75.0	
	9.6	10	75.0	
+O <sub>2</sub> + 4CO	9.8	5	100.0	Sphere, $V_{240}$
	10.0	5	125.0	Pinit.
	10.13	5	150.0	$T_{init.} = 17^\circ C$
	9.48			
	9.68			
	9.95			
	10.16			
	7.13	70	3.0	
	7.5	100	10.0	
	7.72	150	25.0	
+O <sub>2</sub> + 4N <sub>2</sub>	8.20	190	50.0	Sphere, $V_{240}$
	8.47	320	75.0	Pinit.
	8.80	400	100.0	$T_{init.} = 17^\circ C$
	8.88	470	125.0	
	9.03	530	150.0	
	9.23	560	175.0	
	7.80			
	8.00			
	8.30			
	8.65			
+O <sub>2</sub> + 4N <sub>2</sub>	9.14			(79)
	9.37			
	9.45			
	9.76			
	10.17			

Continued on p. 190.



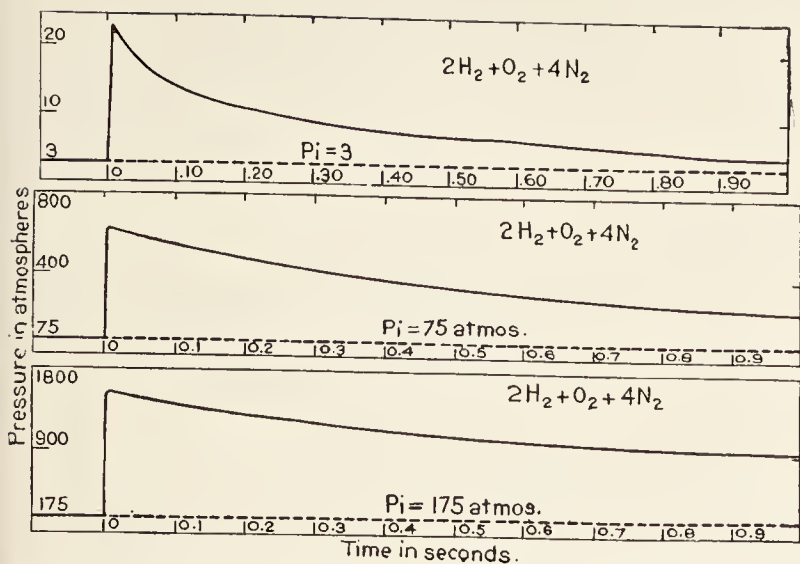


FIG. 11.—Time-pressure curves of  $2\text{H}_2 + \text{O}_2 + 4\text{N}_2$  explosions at initial pressures of 3, 75 and 175 atm. (<sup>73</sup>, <sup>79</sup>). Spherical vessel, 2400 cc capacity.

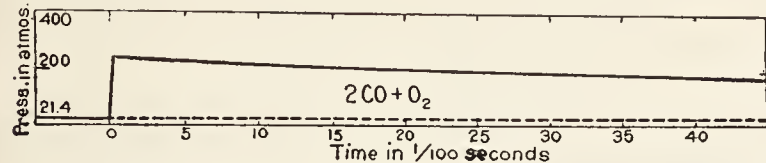


FIG. 12.—Time-pressure curve of  $2\text{CO} + \text{O}_2$  explosion at an initial pressure of 21.4 atm. (<sup>69</sup>). Spherical vessel, 240 cc capacity.

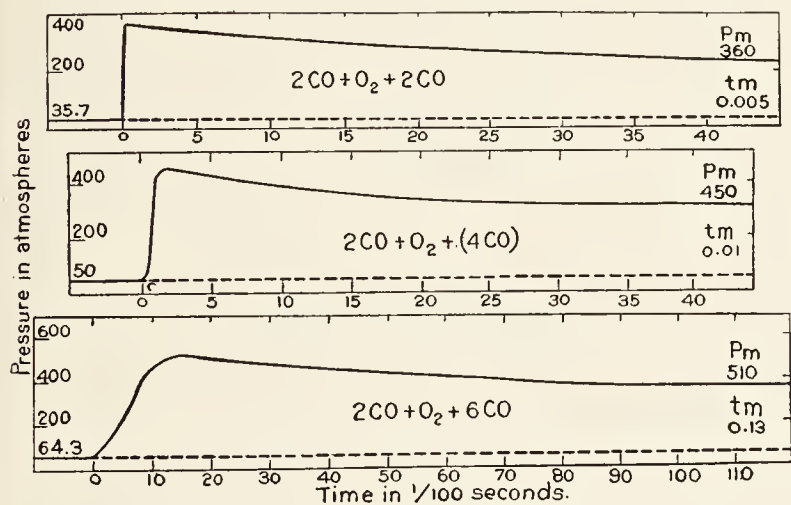


FIG. 13.—Time-pressure curves of  $2\text{CO} + \text{O}_2 + (2\text{CO}, 4\text{CO}, 6\text{CO})$  explosions at initial pressures of 35.7, 50 and 64.3 atm. respt. (<sup>69</sup>).

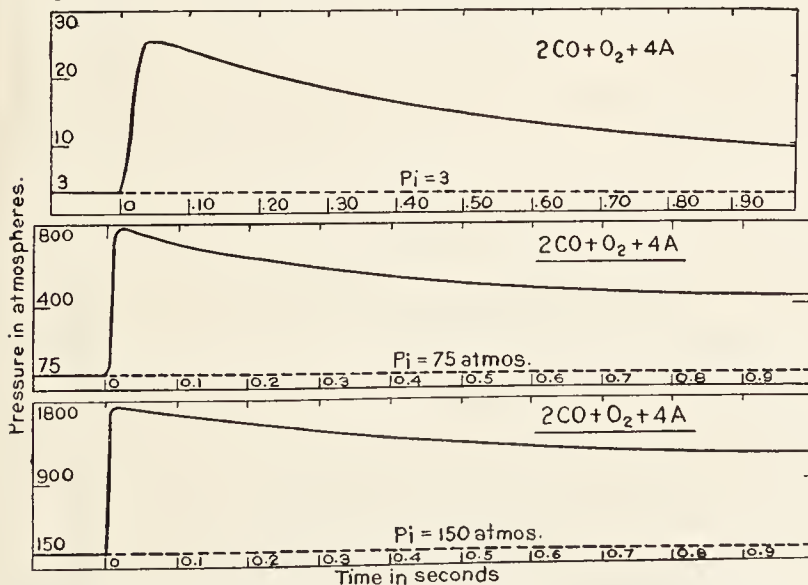


FIG. 15.—Time pressure curves of  $2\text{CO} + \text{O}_2 + 4\text{A}$  explosions at initial pressures of 3.75 (<sup>73</sup>) and 175 atm. (<sup>79</sup>). Spherical vessel, 240 cc capacity.

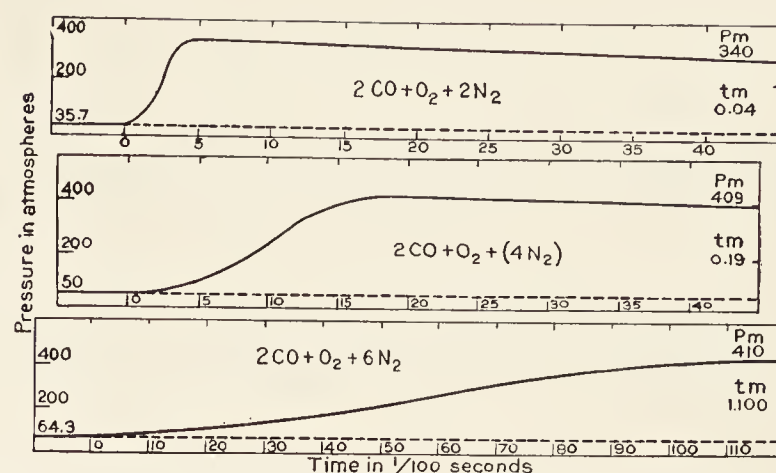


FIG. 14.—Time-pressure curves of  $2\text{CO} + \text{O}_2 + (2\text{N}_2, 4\text{N}_2, 6\text{N}_2)$  explosions at initial pressures of 35.7, 50, and 64.3 atm. respt. (<sup>69</sup>).

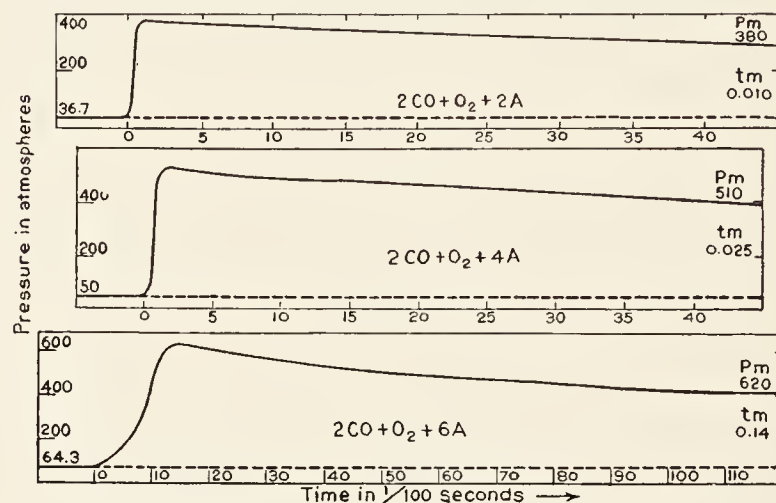


FIG. 16.—Time-pressure curves of  $2\text{CO} + \text{O}_2 + (2\text{A}, 4\text{A}, 6\text{A})$  explosions at initial pressures of 35.7, 50 and 64.3 atm. (<sup>69</sup>).

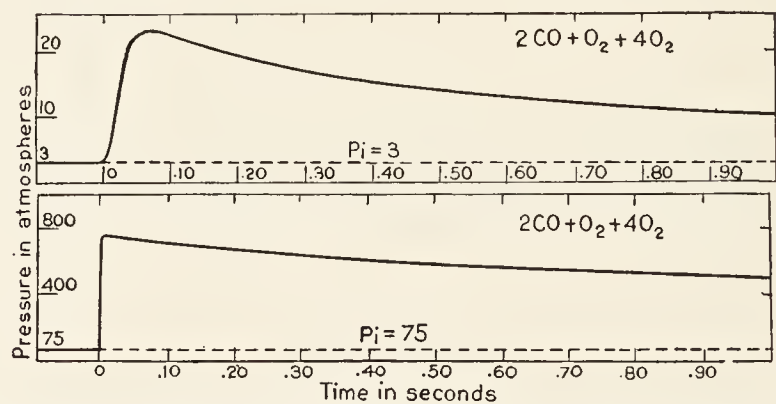


FIG. 17.—Time-temperature curves of  $2\text{CO} + \text{O}_2 + 4\text{O}_2$  explosions at initial pressures of 3 and 75 atm. (<sup>73</sup>). Spherical vessel, 240 cc capacity.

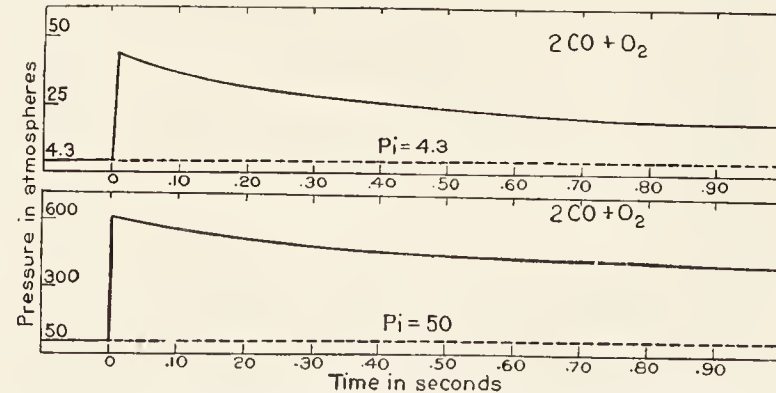


FIG. 18.—Time-pressure curves of  $2\text{CO} + \text{O}_2$  explosions at initial pressures of 4 and 50 atm. (<sup>73</sup>). Spherical vessel, 240 cc capacity.

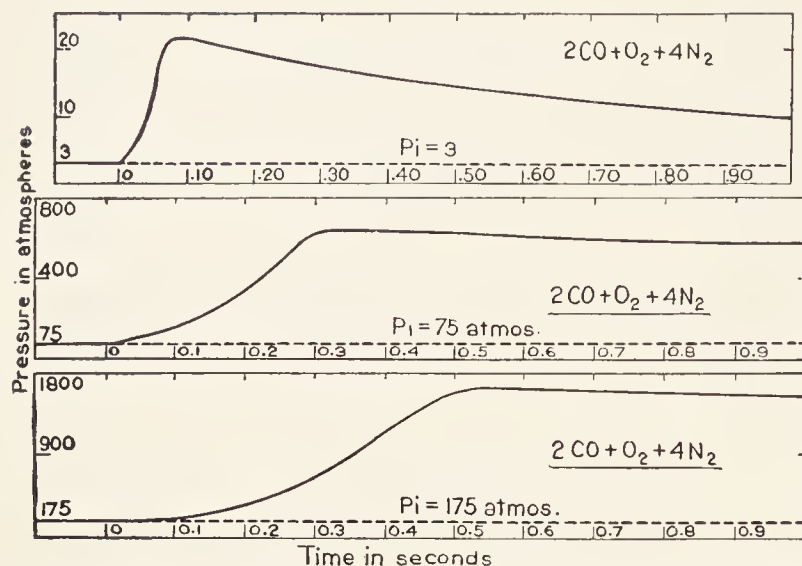


FIG. 19.—Time-pressure curves of  $2\text{CO} + \text{O}_2 + 4\text{N}_2$  explosions at initial pressures of 3 (<sup>79</sup>), 75 and 175 atm. (<sup>73</sup>). Spherical vessel, 240 cc capacity.

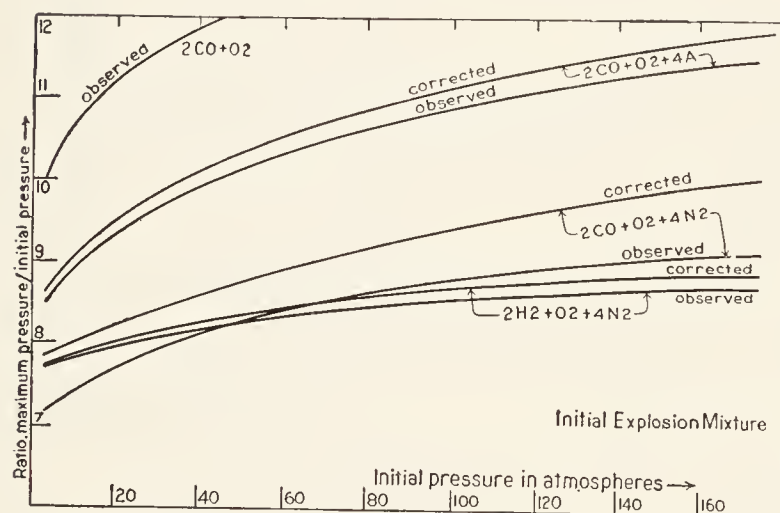


FIG. 20.—Influence of initial pressure on the ratio maximum pressure/initial pressure (<sup>79</sup>). Spherical bomb, capacity 240 cc. The corrected curve gives maximum pressure (corrected for cooling loss during combustion period)/initial pressure (corrected for deviation from Boyle's law).

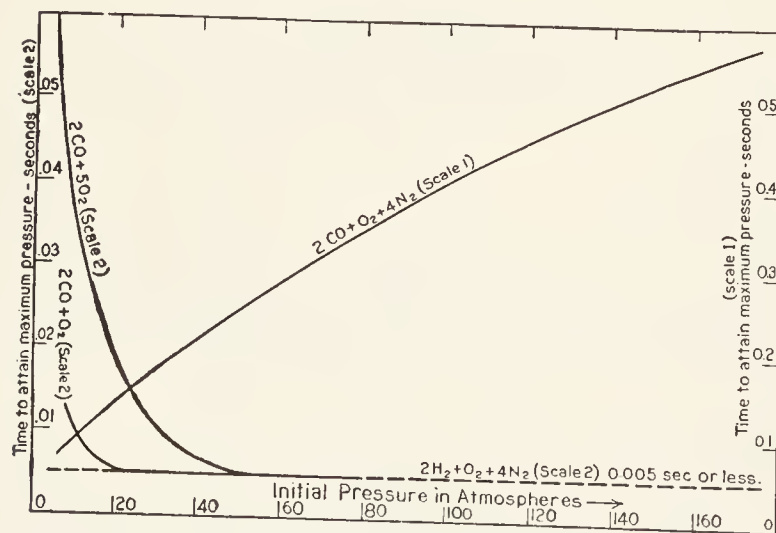


FIG. 21.—Influence of initial pressure on the time taken for the attainment of maximum pressure (<sup>79</sup>). Spherical bomb, capacity 240 cc.

## CO.—(Continued)

Mixture	$\frac{P_{\max.}}{P_{\text{init.}}}$	Milli-sec	Exper. condn.	Lit.
CO + N <sub>2</sub> O + N <sub>2</sub> O % CO (97.5%) in air	10.78	15.40	Cyl., V <sub>4000</sub> V <sub>300</sub>	( <sup>9</sup> ) (11, 15)
20	5.77	800	P <sub>init.</sub> = 2 Sphere V, 16 in. diam.; silver plated interior; central ignition; gas saturated with water vapor at room tem- perature	(76)
25	7.12	385		
30	7.86	231		
35	8.16	211		
40	8.27	175		
45	8.25	170		
50	7.65	189		
55	7.10	251		
60	6.05	390		
65	4.87	920		
25	6.39	280	1	(76)
	7.12	385	2	
	7.10	482	3	
	7.22	550	4	
	7.39	668	5	
	7.24	990	6	
	7.47	1010	7	
30	7.86	231	2	(76)
	8.25	335	4	
	8.85	560	6	
			6	

Influence of the amount of water vapor present. 29.3% CO in air

Vol. H <sub>2</sub> O vapor + 100 of mixture				
0	7.72*	290.2	Cyl. V, 7 in. diam., 8 in. deep T <sub>init.</sub> = 50°C P <sub>init.</sub> = 5	(83)
2.56	7.93*	90.1		
1.68	7.94*	97.0		
1.67	7.94*	92.0		
1.24	7.96*	101.5		
1.21	7.96*	101.0		
0.60	7.94*	125.9		
0.30	7.89*	166.3		

\* Calcd. to T<sub>init.</sub> = 15°.

Mixtures of H<sub>2</sub> and CO

2CO				
+ H <sub>2</sub> + 1½ O <sub>2</sub>	9.28		Cyl., V <sub>4000</sub>	(9, 15)
+ H <sub>2</sub> + 4 O <sub>2</sub>	8.3			
+ 3 H <sub>2</sub> + 1½ O <sub>2</sub>	8.92			
+ 4 H <sub>2</sub> + 3 O <sub>2</sub>	9.08			
2H <sub>2</sub> + O <sub>2</sub>		1.04	Cyl., V <sub>300</sub>	(11)
2CO + O <sub>2</sub>		12.86	Cyl., V <sub>300</sub>	(11)
2H <sub>2</sub>				
+ CO + 1½ O <sub>2</sub>		2.57	Cyl., V <sub>300</sub>	(11)
+ CO + O <sub>2</sub>		1.39	Cyl., V <sub>300</sub>	(11)
H <sub>2</sub>				
+ CO + O <sub>2</sub>		3.88	Cyl., V <sub>300</sub>	(11)
+ 2CO + 1½ O <sub>2</sub>		4.14	Cyl., V <sub>300</sub>	(11)
2(xH <sub>2</sub> + yCO) + O <sub>2</sub> + 4N <sub>2</sub>				
x y				
100 0	8.10*	7.5	Cyl. V, 7 in. diam., 8 in. deep P <sub>init.</sub> = 5 T <sub>init.</sub> = 50°C	(83)
49.7 50.3	8.10*	15.5		
24.3 75.2	8.10*	29.3		
11.9 88.1	8.10*	46.5		
8.0 92.0	8.10*	56.6		
4.1 95.9	8.05*	75.9		
0.2 99.8	7.79*	245.9		
2(xH <sub>2</sub> + yCO) + O <sub>2</sub> + 4N <sub>2</sub>				
100 0	7.82	5	Sphere, V <sub>240</sub> T <sub>init.</sub> = 17°C P <sub>init.</sub> = 50	(67)
50 50	7.98	15		
25 75	8.2	15		
12.5 87.5	8.2	25		
8 92	8.5	25-30		
4 96	8.5	30		
0 100	8.4	180		

\* Calcd. to T<sub>init.</sub> = 15°.



**C<sub>2</sub>H<sub>2</sub> Acetylene**

Mixture	$\frac{P_{\max.}}{P_{\text{init.}}}$	Milli-sec	Exper. condn.	Lit.
C <sub>2</sub> H <sub>2</sub> + 2½O <sub>2</sub>	14.45		Cyl., V <sub>4000</sub>	(9, 15)
C <sub>2</sub> H <sub>2</sub> + 2½O <sub>2</sub>		1.94	Cyl., V <sub>300</sub>	(11)

**C<sub>2</sub>H<sub>4</sub> Ethylene**

C <sub>2</sub> H <sub>4</sub> + 3O <sub>2</sub>	15.25		Cyl., V <sub>4000</sub>	(9, 15)
C <sub>2</sub> H <sub>4</sub> + 3O <sub>2</sub>	14.18	2.86	Cyl., V <sub>300</sub>	(11, 14)
C <sub>2</sub> H <sub>4</sub> + 3O <sub>2</sub>	15.73	2.23	Cyl., V <sub>4000</sub>	(11, 14)

**C<sub>2</sub>H<sub>6</sub> Ethane**

Mixture	$\frac{P_{\max.}}{P_{\text{init.}}}$	Milli-sec	Exper. condn.	Lit.
C <sub>2</sub> H <sub>6</sub> + 3½O <sub>2</sub>	15.30		Cyl., V <sub>4000</sub>	(9)
C <sub>2</sub> H <sub>6</sub> + 3½O <sub>2</sub>		0.83	Cyl., V <sub>300</sub>	(11)
% C <sub>2</sub> H <sub>6</sub> in air			Deduced from a published curve	(56)
3.05	3.8			
3.3	4.9			
3.6	5.75			
4.05	6.85			
4.8	7.8			
5.6	8.3			
6.7	8.75			

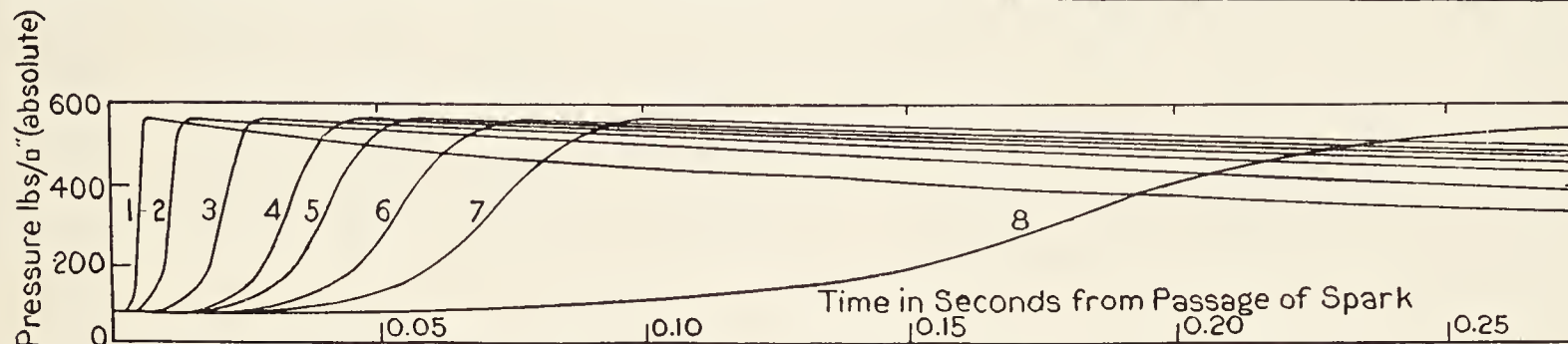


FIG. 22.—Time-pressure curves obtained from the explosion of  $2(x\text{H}_2 + y\text{CO}) + \text{O}_2 + \text{N}_2$  mixtures. Initial pressure, 5 atm. Initial temperature, 50°C. Cylindrical vessels 7" in diam., 8" deep (83)

Curve.....	1	2	3	4	5	6	7	8
H <sub>2</sub> .....	100	50	25	12	8	4	2.2	0.2
CO.....	0	50	75	88	92	96	97.8	99.8

**CH<sub>4</sub> Methane**

CH <sub>4</sub>				
+1.84O <sub>2</sub>	14.35			
+2.80O <sub>2</sub> + 10.5N <sub>2</sub>	7.9			
+1.92O <sub>2</sub> + 7.24N <sub>2</sub>	8.95		Cyl., V <sub>4000</sub>	(13)
+1.44O <sub>2</sub> + 5.41N <sub>2</sub>	7.98			
+2O <sub>2</sub>	15.44		Cyl., V <sub>4000</sub>	(9, 15)
+2O <sub>2</sub>	13.94	1.24	Cyl., V <sub>300</sub>	(11, 14)
+2O <sub>2</sub>	14.81		Cyl., V <sub>4000</sub>	(11, 14)
+O <sub>2</sub> + 4N <sub>2</sub>	5.6	80	Sphere, V <sub>240</sub> ; P <sub>init.</sub> = 50 T <sub>init.</sub> = 17°C	(53)
% CH <sub>4</sub> in air				
6.30	4.20			
6.80	6.10			
7.45	6.64			
7.95	7.09			
8.45	7.40			
9.20	7.73			
9.40	7.80			
9.65	7.90			
10.10	7.97			
10.25	7.97			
10.75	7.87			
11.40	7.73			
12.10	7.36			
12.90	6.78			
13.40	4.80			
13.90	3.50			
6.05	3.86			
6.85	5.35			
7.80	6.85			
8.80	7.66			
9.80	7.94			
10.80	7.80			
11.90	7.40			
12.80	6.78			
12.1	8.15*	275.9		
11.0	8.56*	140.6		
10.5	8.69*	119.3		
9.9	8.70*	105.8		
9.7	8.77*	106.5		
8.5	8.19*	128.8		
7.3	7.20*	225.9		
			Sphere, V <sub>16000</sub> ; highly polished interior surface	(54)
			T <sub>init.</sub> = 100°C Cyl., V, 7 in. diam., 8 in. deep P <sub>init.</sub> = 6.5	(83)

\* Calcd. to T<sub>init.</sub> = 15°, See also p. 177.

**C<sub>2</sub>H<sub>6</sub>O Methyl Ether**

C <sub>2</sub> H <sub>6</sub> O + 3O <sub>2</sub>	18.82		Cyl., V <sub>4000</sub>	(9)
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**C<sub>4</sub>H<sub>10</sub>O Ethyl Ether**

C <sub>4</sub> H <sub>10</sub> O + 6O <sub>2</sub>	15.42		Cyl., V <sub>4000</sub>	(9)
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**C<sub>2</sub>N<sub>2</sub> Cyanogen**

C <sub>2</sub> N <sub>2</sub>				
+ O <sub>2</sub> + 4N <sub>2</sub>	10.95		Cyl., V <sub>18</sub>	(2)
+2O <sub>2</sub>	19.80			
+N <sub>2</sub> + 2O <sub>2</sub>	16.72			
+2N <sub>2</sub> + 2O <sub>2</sub>	13.93			
+4N <sub>2</sub> + 2O <sub>2</sub>	11.66			
+O <sub>2</sub>	23.72			
+½N <sub>2</sub> + O <sub>2</sub>	19.52			
+2N <sub>2</sub> + O <sub>2</sub>	14.42			
+4N <sub>2</sub> + O <sub>2</sub>	11.14			
+4NO	16.00			
+N <sub>2</sub> O	21.40			
+2NO	22.08			
+2N <sub>2</sub> O	24.6			
+O <sub>2</sub>		1.06	Cyl., V <sub>300</sub>	(11)
+2O <sub>2</sub>		1.55	Cyl., V <sub>300</sub>	(11)
+2O <sub>2</sub>		4.50	Sphere, V <sub>1500</sub>	(11)
+2O <sub>2</sub> + 2N <sub>2</sub>		15.4	Cyl., V <sub>300</sub>	(11)
+2O <sub>2</sub> + N <sub>2</sub>		6.09	Cyl., V <sub>300</sub>	(11)
+O <sub>2</sub> + ¾N <sub>2</sub>	18.65	3.20	Cyl., V <sub>300</sub>	(11)
+O <sub>2</sub> + ¾N <sub>2</sub>	21.09	2.74	Sphere, V <sub>1500</sub>	(11)
+O <sub>2</sub> + 3N <sub>2</sub>	13.88	10.35	Cyl., V <sub>300</sub>	(11)
+O <sub>2</sub> + 3N <sub>2</sub>	15.56	15.12	Sphere, V <sub>1500</sub>	(11)
+O <sub>2</sub> + 3N <sub>2</sub>		23.63	Cyl., V <sub>300</sub>	(11)
+O <sub>2</sub> + 4N <sub>2</sub>	10.6	29.78	Cyl., V <sub>300</sub>	(11)
+4N <sub>2</sub> O		4.53	Cyl., V <sub>300</sub>	(11)
+4N <sub>2</sub> O	12.02		Sphere, V <sub>1500</sub>	(11)

**C<sub>6</sub>H<sub>6</sub> Benzene (82)**

Mixture	$\frac{P_{\max.}}{P_{\text{init.}}}$	Milli-sec	Exper. condn.
16.84	8.28	105.1	
14.76	9.00	73.5	T <sub>init.</sub> = 100°C
13.24	9.50	59.7	P <sub>init.</sub> = 95 lbs./in. <sup>2</sup>
13.16	9.50	59.8	Cyl., V, 7 in. diam., 8 in. deep
12.06	9.74	55.1	
10.7	9.78	49.0	
9.15			Loud metallic knock

C<sub>6</sub>H<sub>14</sub> Hexane (82)

Mixture	$\frac{P_{max.}}{P_{init.}}$	Milli-sec	Exper. condn.
16.91	8.86	91.2	$T_{init.} = 100^{\circ}\text{C}$
14.80	9.48	69.5	$P_{init.} = 95 \text{ lbs./in.}^2$
13.97	9.56	64.0	Cyl., V, 7 in. diam.,
13.20	9.50	58.6	8 in. deep
10.72	Violent explosion		

Petrol (82)

Ratio air/fuel by wt.	$\frac{P_{max.}}{P_{init.}^*}$	Milli- sec	Exper. condn.	
			$\frac{P_{init.}}{\text{lbs./in.}^2}$	
19.2	7.74	175.2	95.2	$T_{init.} = 100^{\circ}\text{C}$ Cyl., V, 7 in. diam., 8 in. deep
16.9	8.58	109.6	95.5	
	8.52	110.8	142.5	
14.8	9.33	78.4	95.5	
13.0	9.71	67.1	95.7	
10.7	Loud metallic knock		95.3	

\* Calcd. to  $T_{init.} = 15^{\circ}\text{C}$ .

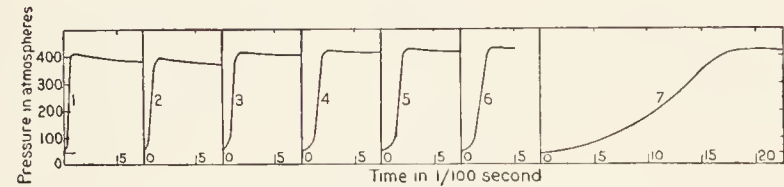


FIG. 23.—Time-pressure curve obtained from the explosion of  $2(x\text{H}_2 + y\text{CO}) + \text{O}_2 + 4\text{N}_2$  mixtures. Initial pressure, 50 atm., room temperature. Spherical vessel, 240 cc capacity (67, 71).

Curve.....	1	2	3	4	5	6	7
H <sub>2</sub> .....	100	50	25	12.5	8	4	0
CO.....	0	50	75	87.5	92	96	100

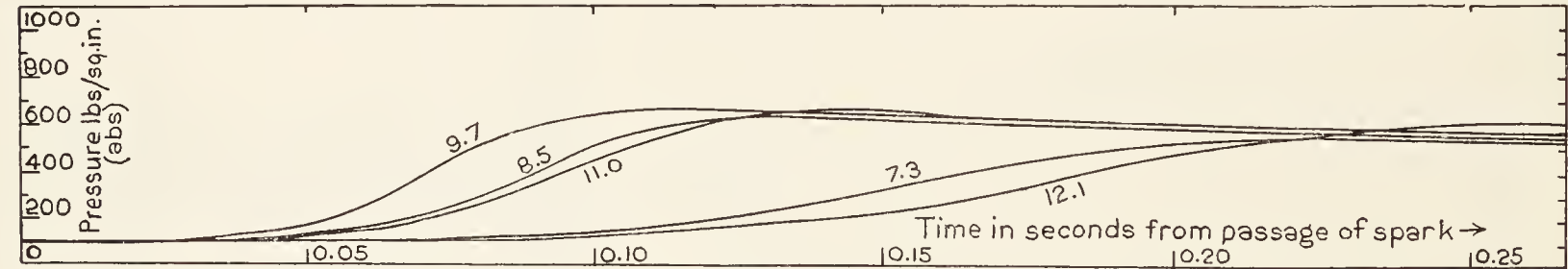


FIG. 24.—Time-pressure curves obtained from the explosion of methane-air mixtures. Initial pressure, 95.1 lb./in.<sup>2</sup> Initial temperature, 100°C (83).

EFFECT OF INITIAL TEMPERATURE AND PRESSURE

C<sub>6</sub>H<sub>6</sub> Benzene (82)

$T_{init.}$ °C	$P_{init.}$ lbs./in. <sup>2</sup>	Maximum pressure rise (lbs./in. <sup>2</sup> ) ratio air/fuel by wt.		
		12.0	10.7	9.15
100	95.0	645	644	
	67.0	447	449	
	38.0	242	248	241
200	120.5	636		646
	84.5	438		442
	48.2	238		240
300	146.0	614		633
	102.0	420		434
	58.0	226		237

INFLUENCE OF TEMPERATURE AND PRESSURE

Mixture: 9.9% CH<sub>4</sub> in air. Cyl. V, 7 in. diam., 8 in. deep

$T_{init.}$ °C	$P_{init.}$ lb./in. <sup>2</sup>	$\frac{P_{max.}}{P_{init.}}$	$\frac{P_{max.}}{P_{init.}}$	Milli- sec
24.7	30.3	8.32	8.57*	99.7
24.7	53.0	8.41	8.65*	11.63
100	38.1	6.79	8.51*	79.8
100	66.7	6.79	8.52*	104.7
100	95.0	6.95	8.71*	109.0
200	48.2	5.60	8.57*	68.2
200	84.4	5.65	8.64*	75.0
200	120.6	5.66	8.69*	83.8
300	58.2	4.68	8.36*	49.6
300	102.3	4.75	8.48*	59.7
300	145.9	4.80	8.57*	67.1
400	68.5	4.12	8.30*	41.0
400	120.1	4.12	8.30*	47.3
400	171.5	4.19	8.56*	54.8

\* Calcd. to  $T_{init.} = 15^{\circ}\text{C}$ .

EFFECT OF INITIAL TEMPERATURE AND PRESSURE

Petrol, Hexane and Benzene (82)

$T_{init.}$ °C	$P_{init.}$ lbs./in. <sup>2</sup>	Pressure rise (lbs./in. <sup>2</sup> ) ratio air/fuel by wt.		
		Petrol	Hexane	Benzene
100	100	13	14	12
	50	660	668	680
200	100	321	324	327
	50	519	520	523
	50	250	250	248

MEASUREMENTS OF EXPLOSION TEMPERATURES

Temperature Distribution at Moment of Maximum Pressure

Ten per cent coal gas (680 BTU/ft.<sup>3</sup>) (31). Vessel (Fig. 25):  
Capacity 6.2 ft.<sup>3</sup>

Mean temperature (inferred from pressure)..... 1600°C  
(a) Temperature at center near spark (B)..... 1900°C  
(b) Temperature 10 cm within wall (C)..... 1700°C  
(c) Temperature 1 cm from wall (D)..... 1100°-1300°C  
(d) Temperature 1 cm from wall (at the side)..... 850°C

Temperature Distribution 0.5 sec after Maximum Pressure

Mean temperature throughout the gas..... 1100°C  
Mean temperature of gas excluding a layer 1 cm thick in  
contact with the walls..... 1160°C



# DIRECT MEASUREMENT OF THE TEMPERATURE-CYCLE IN A GAS ENGINE (47); cf. (18, 20, 38)

Coal gas (460 BTU/ft.<sup>3</sup>); cylinder 7 in. diameter; stroke 15 in.; working volume 577 in.<sup>3</sup>; thermocouple: 10% alloys of Pt-Rh and Pt-Ir (0.0005–0.0008 in. thick).

No.....	1	2	3	4	5
Ratio Air/ Gas..	7.35/1	7.08/1	7.13/1	6.71/1	5.66/1
Jacket outlet, °C	35.6	37.2	81.4	40.6	52.8
Angle of crank	Temp., °C	Temp., °C	Temp., °C	Temp., °C	Temp., °C
360	569	568	582	705	636
300	496	503	515	624	540
240	349	348	371	517	431
180	256	269	317	422	371
120	217	223	262	365	330
60	228	241	273	326	337
30	267	275	330	339	442
720					2249
710				1947	
709					
708				1889	
705		1848	1871		1918
697	1836				
690	1546	1551	1532	1579	1721
675	1423	1418	1397	1437	1586
660	1154	1147	1269	1247	1417
645	1159	1124	1139	1193	1275
630	1041	1052	1018	1098	1192
615	1022	1007	1017	1058	1124
600	1017	975	975	982	1068
540	856	843	816	895	889
480	726	708	704	794	764
420	648	646	637	751	705

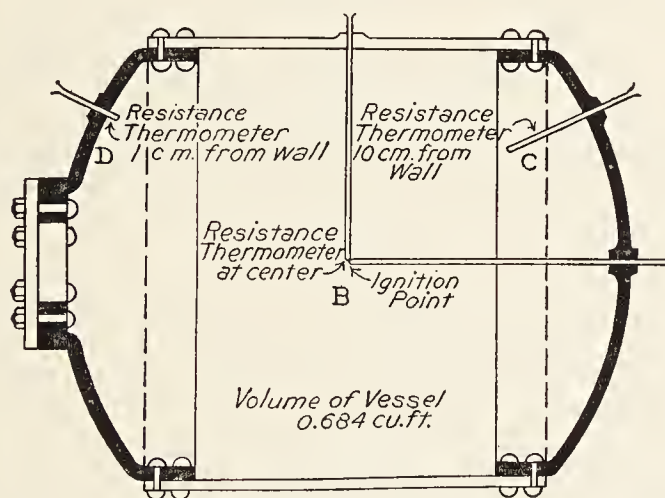


FIG. 25.—Explosion vessel.

## RADIATION LOSSES

Pressure-time curves obtained from the explosion of a 15% coal gas (675 BTU/ft.<sup>3</sup>)—air mixture in an explosion vessel: (a) with a highly polished, (b) with a blackened interior surface (44); volume of vessel 0.788 ft.<sup>3</sup>; area of interior surface 4380 cm<sup>2</sup>.

Maximum pressure for initial pressure 1 atmosphere	Pressure lb./in. <sup>2</sup> for seconds after ignition			
	0.15	0.25	0.35	0.45
(a) 114.0 lb./in. <sup>2</sup> .....	98.7	84.2	73.5	64.9
(b) 110.8 lb./in. <sup>2</sup> .....	89.2	73.1	61.3	53.5

Same for 9.8% coal gas (575 BTU/ft.<sup>3</sup>) (45). Vessel as above

Time from ignition	Mean temperature °K, inferred from pressure	Mean radiation received per cm <sup>2</sup> of wall	Total loss of heat by radiation, % heat of combustion
0.15	1600	0.12	5.0
0.18	1700*	0.17	7.0
0.20	1680	0.21	8.7
0.25	1600	0.28	11.6
0.50	1280	0.46	19.0
0.75	1085	0.54	22.3
1.00	950	0.57	23.6

\* Maximum temperature.

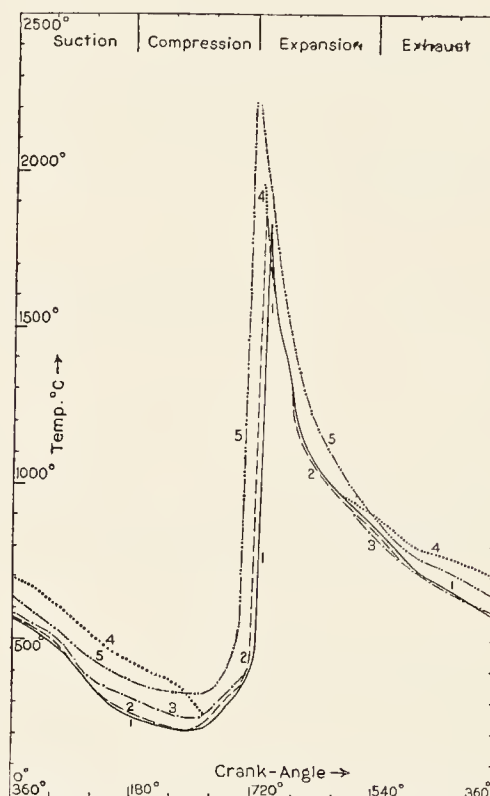


FIG. 26.—Direct measurement of temperature-cycle in a gas engine (47).

## INFLUENCE OF DENSITY OF GAS ON RADIATION LOSS

Fifteen per cent coal gas (575 BTU/ft.<sup>3</sup>)—air mixture (45)

Time from ignition, sec	Mean temperature °K, of gas (inferred from pressure)		Mean radiation received per cm <sup>2</sup> of wall		Total heat loss by radiation, % heat of combustion	
	$P_i = \frac{1}{2}$ at.	$P_i = 1\frac{1}{2}$ at.	$P_i = \frac{1}{2}$ at.	$P_i = 1\frac{1}{2}$ at.	$P_i = \frac{1}{2}$ at.	$P_i = 1\frac{1}{2}$ at.
0.05	2270	2400	0.061	0.14	3.3	2.5
0.10	2020	2210	0.2	0.425	11.0	7.7
0.15	1790	2040	0.29	0.615	15.9	11.3
0.20	1600	1890	0.35	0.75	19.2	13.6
0.25	1440	1765	0.39	0.843	21.4	15.3
0.50	1030	1350	0.47	1.065	25.7	19.3
0.75	810	1140	0.49	1.143	26.8	20.7
1.00	700	1010	0.492	1.158	26.9	21.0

## HYDROGEN—AIR MIXTURES (61)

Strength of mixture	Maximum temperature °K, developed (inferred from pressure)	Time of explosion (sec)	Total radiation received per cm <sup>2</sup> of wall	% heat of combustion lost by radiation up to max. pressure	Total heat loss by radiation, % heat of combustion
25.4	2400	0.017	0.60	0.5	16.1
15.3	1580	0.065	0.245	1.3	11.0
10.0	1230	0.240	0.12	1.4	8.2

## Compared with coal gas

15.0	2410	0.05	0.98	3.3	26.1
13.0	2170	0.07	0.81	3.7	25.0
9.8	1700	0.18	0.57	7.0	23.6

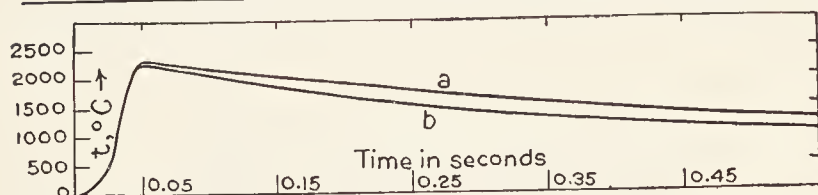


FIG. 27.—Pressure-time curves obtained from the explosion of a 15 % coal gas air mixture (44).

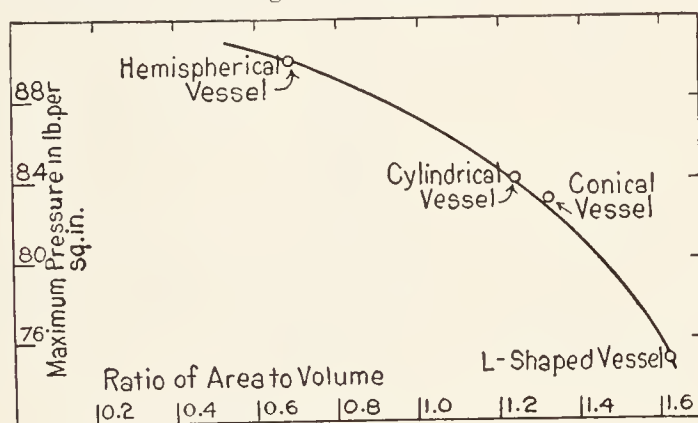


FIG. 28.—Influence of shape of explosion vessels having the same initial capacity on the maximum pressure developed (68).

## HEAT LOSS

Mixture of 15% coal gas (570 BTU/ft.<sup>3</sup>) in air (64)

Sec*	Mean † gas temperature, °K	Heat loss/cm <sup>2</sup> , % heat of combustion of the coal gas		
		Conduction	Radiation	Total
0.05	2440‡	5.1	3.8	8.9
0.1	2220	14.4	10.4	24.8
0.15	2020	20.3	15.0	35.3
0.2	1840	24.5	17.9	42.4
0.25	1710	27.7	20.3	48.0
0.3	1600	30.0	22.2	52.2
0.4	1430	34.4	24.3	58.7
0.5	1300	37.6	25.6	63.2

\* Time after ignition in seconds.

† Inferred from pressure.

‡ Maximum temperature.

## Various Formulae for Approximate Estimation of Cooling Losses in Explosions of Coal Gas—Air Mixtures

General formula for radiation loss in coal gas—air explosions (59)

$$R_T = 0.0001 (T_{\max} - 700\sqrt{D \times L})$$

where

 $R_T$  = Total radiation registered $T_{\max}$  = Maximum temperature (mean, °K) $D$  = Density of the gaseous mixture in atmospheres $L$  = Length of the explosion cylinder in cmRate of loss of heat by radiation, cm<sup>2</sup> of wall surface/sec ( $R_L$ ) (64)

$$R_L = 1.75 \times 10^{-14} \theta^4$$

where

 $\theta$  = mean absolute temperature.For a cylindrical vessel ( $h$  cm diam.  $\times$   $h$  cm deep):

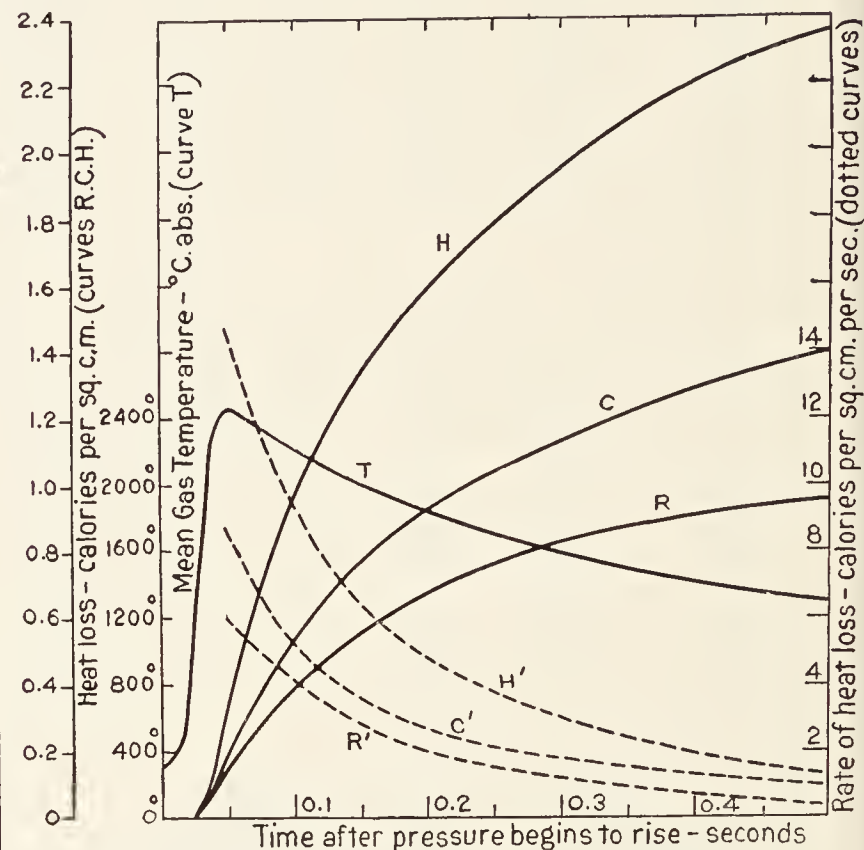
$$R_L = 0.32 \times 10^{-14} \theta^4 \sqrt{h}$$

Rate of loss of heat by conduction, cm<sup>2</sup> of wall surface/sec ( $R_c$ ) (64):

$$R_c = 4 \times 10^{-13} (t - t_w)^4$$

for temperatures above 2000°K;

$$R_c = 7 \times 10^{-10} (t - t_w)^3$$

for temperatures below 2000°K where  $(t - t_w)$  is the temperature difference, °C, between the hot gases and the walls of the explosion vessel.FIG. 29.—Heat loss from 15 % mixture of coal gas and air (64, 74).  $R$  = mean loss of heat by radiator per cm<sup>2</sup> of wall surface.  $C$  = mean loss of heat by conductor per cm<sup>2</sup> of wall surface.  $H$  = total heat loss.  $R'$ ,  $C'$  and  $H'$  give the rate of heat loss by radiation, conduction and total loss, respectively.  $T$  = mean gas temperature (deduced from the pressure).Rate of total heat loss, cm<sup>2</sup> of wall surface/sec ( $H_T$ ) in a cylinder ( $h$  cm diam.  $\times$   $h$  cm deep) (64):

$$H_T = 4 \times 10^{-13} (T - T_w)^4 + 0.32 \times 10^{-14} T^4 \sqrt{h}$$

for temperatures above 2000°K;

$$H_T = 7 \times 10^{-10} (T - T_w)^3 + 0.32 \times 10^{-14} T^4 \sqrt{h}$$

for temperatures below 2000°K.

Total heat loss to walls of cylindrical explosion vessel (30 cm  $\times$  30 cm up to moment of maximum pressure (64) (coal gas—air explosions) at atmospheric density:

$$H_{\max} = 2.15 \times 10^{-8} \theta_{\max}^{2.5} \times t_e$$

or expressed as a proportion of the heat of combustion

$$H_{c \max} = 1.43 \times 10^{-5} \theta_{\max}^{1.5} \times t_e$$

where  $t_e$  is the explosion time.

Total heat loss per unit area in similar engines working under similar conditions may be given by the equation (74):

$$H = C + R\sqrt{d}$$

where

 $C$  = conduction loss per unit area $R\sqrt{d}$  = radiation loss per unit area in an engine of diameter  $d$



## INFLUENCE OF TURBULENCE

Explosions of coal gas—air mixtures in conical vessel, capacity 115 in.<sup>3</sup> (ignition at vertex) (68); cf. (7, 31, 39, 56, 75)

Ratio air/coal gas	$\frac{P_{\max.}}{P_{\text{init.}}}$		Milli-sec	
	With turbulence	Quiescent	With turbulence	Quiescent
2.08	6.92		70.0	
2.61	7.23	6.44	28.0	95.0
3.13	7.48	6.68	39.0	71.0
3.65	7.24		38.0	
4.17	6.70	6.30	51.6	83.0
5.21	6.13	5.52	49.6	139.0
6.25	5.53	4.70	81.0	329.0
7.29	4.84	3.76	136.0	942.0
8.33	4.15		344.0	

Ethane, C<sub>2</sub>H<sub>6</sub>, and air mixtures in spherical vessel, capacity 4000 cm<sup>3</sup> (sparked at center) (56)

% C <sub>2</sub> H <sub>6</sub> in air	Milli-sec	
	Quiescent	Turbulence
3.30		176
3.45		96
3.60	332	
3.80	152	
3.85	146	45
4.05	124	36
4.30		33
4.35	94	
4.60		26
4.65	73	
4.70		29
4.80	70	
5.00	63	24
5.25		21
5.35	54	20
5.60	52	
5.95		19
6.00	46.5	
6.40		19
6.45	46	
6.75	46.5	19
7.05	50	20
7.15	52	

## Distribution of Energy at the Moment of Maximum Pressure

Coal gas—air explosions (64)

*Internal Thermal Energy.*—From 72% of the heat of combustion in a 9.7% coal gas—air mixture to 80% in a 15% mixture.

*Available Chemical Energy.*—About 10% in each case.

*Heat Loss to Walls of Vessel.*—From about 10% in a 15% mixture to about 18% in a 9.7% mixture.

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## ANIMAL AND VEGETABLE OILS, FATS AND WAXES

C. AINSWORTH MITCHELL

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## INTRODUCTION

**The General Property Table.**—In Table 2, the oils and fats are first classified according to the Alder Wright system. Under each class, the individuals are arranged in alphabetical order of their generic names; and each individual is given a *General Index No.* by means of which it is identified in all subsequent tables. Where only one series of values is given, the data are usually those recorded for a single specimen of the particular oil. Table 2 serves therefore as a general finding table based upon the scientific names. If the scientific name is not known to the reader, he should first consult Table 1 and obtain the General Index No.

**Supplementary Tables.**—Properties not covered by Table 2 are set forth in Tables 3 to 17 inclusive.

**Property-Substance Tables.**—In these tables (Tables 18 to 27, inclusive) the individuals are arranged by index number in ascending order of the value of the property, the intervals on the scale of property values being indicated in bold-face type. These property-substance tables may be used (1) to select an individual having any desired value of a given property, or (2) to identify (in some cases at least) an individual by means of its properties. For the latter purpose, the properties cited in the following example are most useful.

*Example;* An oil is found by test to have the following properties: Congealing point, 0°; saponification, 190; iodine, 82; acetyl,

## INTRODUCTION

**Table des propriétés générales.**—Dans la Table 2, les huiles et les graisses sont d'abord classées suivant le système d'Alder Wright. Dans chaque classe, les huiles et graisses sont rangées suivant l'ordre alphabétique de leurs noms génériques et on leur a attribué un "numéro index général" au moyen duquel elles seront identifiées dans toutes les tables suivantes. Où on a donné seulement une série de valeurs, les données sont généralement ceux d'un seul échantillon de l'huile particulière. La Table 2 est donc une table de recherche générale, basée sur les noms scientifiques. Si le nom scientifique n'est pas connu du lecteur, il devra d'abord consulter la Table 1 afin d'obtenir le "numéro index général."

**Tables supplémentaires.**—Les propriétés qui ne sont pas mentionnées dans la Table 2 sont contenues dans les Tables 3 à 17 inclusivement.

**Tables des propriétés des substances.**—Dans ces tables (Tables 18 à 27 inclusivement), les huiles et graisses représentées par leur nombre index sont arrangées suivant l'ordre ascendant de la valeur de la propriété, les intervalles de l'échelle des valeurs de la propriété étant indiqués en caractères gras. Ces tables des propriétés des substances peuvent être utilisées: 1) pour choisir une huile ou graisse possédant une valeur désirée d'une propriété donnée, ou 2) pour identifier (au moins dans quelques cas) une huile ou graisse au moyen de ses propriétés. On se servira alors de



11; unsaponifiables, 0.6; fatty acids, M. P., 28°; "titer," 21°;  $n_D^{25}$ , 1.466. From each of Tables 20, 23, 22, 21, 26, 27 and 16B, write down a list of the General Index Nos. lying in the neighborhood of the experimental value and arrange each list in ascending order of these numbers. Determine the number of times each Index No. occurs in this set of lists. For the present example, this gives the following result: 8 times, No. 8; 7 times, No. 31; 4 times, Nos. 3, 5, 26, 47, 62, 91; 3 times, Nos. 13, 20, 29, 33, 54, 61, 67, 83, 84, 92.

By turning to Table 2 and examining the properties there recorded for these oils, all but Nos. 8 and 31 are definitely eliminated. The oil under examination must, therefore, be either olive oil or neat's foot oil, or some oil closely resembling these but not included in Table 2. A further comparison of Nos. 8 and 31 results in the elimination of No. 31 on the basis of the acetyl and iodine values, but additional confirmatory tests are necessary.

**Definitions.**—v. p. viii.

## EINLEITUNG

**Die Haupteigenschaften Tafel.**—In der Tafel 2 werden die Öle und Fette zuerst entsprechend dem Alder Wright System klassifiziert. In jeder Klasse sind die einzelnen Fette und Öle in alphabetischer Ordnung mit deren Gattungsnamen angeordnet, wobei jedem eine "General Index No." zu geordnet ist mit der es in den folgenden Tafeln erkannt werden kann. Ist nur eine Serie von Werten angegeben, so beziehen sich diese gewöhnlich auf eine einzelne Probe des bezeichneten Öles. Tafel 2 dient daher allgemein zum Nachschlagen, mit den wissenschaftlichen Namen als Grundlage. Ist dem Leser der wissenschaftliche Name nicht bekannt, so wäre zuerst die Tafel 1 heranzuziehen, wo die General Index No. erhalten wird.

**Ergänzende Tafeln.**—Eigenschaften die sich nicht in der Tafel 2 vorfinden, sind in den Tafeln 3 bis einschliesslich 17 enthalten.

**Eigenschaften Tafeln.**—In diesen (Tafel 18 bis einschliesslich 27) sind die einzelnen Öle und Fette nach ihren Index Nummern in aufsteigender Ordnung ihrer Eigenschaftswerte gereiht, wobei die Intervalle an der Skale der Eigenschaftswerte durch hervorgehobene Schrift angezeigt werden. Diese Eigenschaften Tafeln wären zu benützen: 1) Um ein besonderes Öl oder Fett heranzuziehen, welches ihrgegend einen gewünschten Wert einer gegebenen Eigenschaft hat. 2) Zur Erkennung (wenigstens in einigen Fällen) eines besonderen Öles oder Fettes auf Grund seiner Eigenschaften. In diesem zweiten Falle ist es am nützlichsten die Eigenschaften in der Art des folgenden Beispieles festzulegen.

**Beispiel:** Von einem Öl wurden durch Untersuchung folgende Eigenschaften gefunden: Erstarrungspunkt 0°; Verseifungszahl 190; Jodzahl 82; Azetylzahl 11; Unverseifbares 0,6; Fettsäure: Sm. P. 28°; Erstarrungs-Punkt 21°;  $n_D^{25}$  = 1,466. Aus jeder der Tafeln, 20, 23, 22, 21, 26, 27; und 16B schreibe man eine Liste der General Index Nummern heraus, welche in der Nähe der experimentell bestimmten Grösse liegen, wobei in der Liste die Nummern in aufsteigender Reihenfolge anzuordnen sind. Dann bestimmt man wie oft jede einzelne Index Nummer in der Liste anzutreffen ist. Für das vorliegende Beispiel bekommt man als Ergebnis: 8 mal No. 8, 7 mal No. 31, 4 mal No. 3, 5, 26, 47, 62, 91, 3 mal No. 13, 20, 29, 33, 54, 61, 67, 83, 84, 92.

Verwendet man die Tafel 2 und prüft die für diese Öle hier angegebenen Eigenschaften, so findet man, dass bis auf No. 8 und No. 31, alle anderen ausscheiden. Das gesuchte Öl ist daher entweder Olivenöl oder Klauenöl, oder ihrgegend ein Öl, welches den genannten zwei sehr eng verwandt sein muss und nicht in der Tafel 2 enthalten ist. Ein weiterer Vergleich von No. 8 und No. 31 gibt, dass No. 31 auf Grund der Azetyl- und Jodzahl wegfällt. Besondere bestätigende Untersuchungen sind jedoch notwendig.

**Definitionen.**—v. p. viii.

préférence des propriétés citées dans l'exemple suivant, qui sont les plus utiles pour atteindre ce but.

**Exemple:** On a trouvé expérimentalement qu'une huile possède les propriétés suivantes: point de congélation 0°; indice de saponification, 190; indice d'iode, 82; indice d'acétyle, 11; insaponifiable 0,6; acides gras Pt. F., 28°, Pt. S., 21°;  $n_D^{25}$ , 1,466. On consulte alors les Tables 20, 23, 22, 21, 26, 27 et 16B et on dresse pour chacune des tables la liste des "numéros index général" qui se trouvent dans le voisinage de la valeur expérimentale, en disposant dans chaque liste ces numéros dans l'ordre ascendant. Ensuite on détermine combien de fois chaque numéro index se trouve dans l'ensemble des différentes listes. Pour l'exemple indiqué, on obtient les résultats suivants: 8 fois le No. 8; 7 fois le No. 31; 4 fois les Nos. 3, 5, 26, 47, 62, 91; 3 fois les numéros 13, 20, 29, 33, 54, 61, 67, 83, 84 et 92.

En se référant à la Table 2 et en examinant les propriétés qui y sont mentionnées relativement à ces huiles, on peut éliminer tous les numéros à l'exception des Nos. 8 et 31. L'huile à déterminer doit donc être ou de l'huile d'olive, ou de l'huile de pied de boeuf, ou une huile présentant une ressemblance étroite avec celles-ci, mais non mentionnée dans la Table 2. D'une comparaison ultérieure des Nos. 8 et 31, il résulte l'élimination du No. 31, sur la base les indices d'acétyle et d'iode, mais des essais supplémentaires confirmant la chose sont nécessaires.

## INTRODUZIONE

**Tabella delle proprietà principali.**—Nella Tabella 2 gli olii ed i grassi sono anzitutto classificati secondo il sistema di Alder Wright. In ogni classe essi sono disposti in ordine alfabetico in base al nome comune, e ad ognuno è assegnato un numero indice che serve a riconoscerlo nelle tabell successive. Data una sola serie di valori, questi sono in generale quelli di uno solo campione del olio particolare. La Tabella 2 serve perciò come tabella generale di riscontri in base ai nomi scientifici. Se il lettore non conosce il nome scientifico, deve consultare prima la Tabella 1 dove trova il numero indice.

**Tabelle supplementari.**—Le proprietà che non si trovano nella Tabella 2, sono contenute nelle tabelle da 3 a 17 inclusa.

**Tabelle delle proprietà.**—In queste (da 18 a 27 inclusa) i singoli olii e grassi sono disposti nell'ordine crescente delle loro proprietà in base ai numeri indici: gli intervalli nella scala dei valori delle proprietà sono indicati con caratteri in grassetto.

Queste tabelle di proprietà possono servire: 1) per scegliere una sostanza che abbia un determinato valore di una certa proprietà, oppure, 2) per identificare (in alcuni casi almeno) una sostanza in base alle sue proprietà. A questo ultimo scopo sono soprattutto utili le proprietà citate nel seguente esempio.

**Esempio.**—Si sia trovato che un olio ha le seguenti proprietà: Punto di congelamento 0°; numero di saponificazione 190; numero di iodio 82; numero di acetile 11; insaponificabile 0,6; punto di fusione degli acidi grassi 28°, punto di solidificazione 21°;  $n_D^{25}$ , 1,466.

Da ognuna delle Tabelle 20, 23, 22, 21, 26, 27 e 16B si ricava allora una lista di numeri indici con valori delle proprietà vicini a quelli sperimentali e si dispone ogni lista con questi valori in ordine crescente. Si osserva quindi quante volte ogni numero indice figura in questa serie di elenchi. Nel caso presente si ha: 8 volte il numero 8; 7 volte il numero 31; 4 volte i numeri 3, 5, 26, 47, 62, 91; 3 volte i numeri 13, 20, 29, 33, 54, 61, 67, 83, 84, 92.

Se ora si considera la Tabella 2 e si esaminano le proprietà ivi riportate per questi olii, essi vengono ad essere tutti scartati tranne i numeri 8 e 31. L'olio in esame perciò deve essere olio di oliva, oppure olio di piede di bue, o un olio che rassomiglia molto a questi due, ma che non è compreso nella Tabella 2.

Confrontando ancora i numeri 8 e 31, si scarta pure il 31 in base ai numeri di acetile e di iodio.

E' necessario però confermare ulteriormente questo risultato.

## 1. INDEX OF COMMON NAMES

## English

(In the following index the word "oil" has been omitted. The various entries are oils unless specifically classified as "fats," "waxes," etc.)

Aburachan seed, 127	Corn, 51	Mabula panza, 141	"Pitch tree," 78
Acorn, 46	Cotton, 124	Macassar, 145	Plum kernel, 16
Akebia, 97	Cottonseed, 41	Mace butter, 136	Pongam, 143
Akee, 109	Coumu, 139	Madia, 45	Poona fat, 113
Akoon fat, 112	Crab, 4	Mafura, 131	Poppy seed, 69
Almond, 13	Croton, 37	Mahua butter, 105	Porpoise, 89
Anaja, 133	Cupu, 148	Maize, 51	Pumpkin seed, 38
Apricot kernel, 14	Curcas, 26	Malabar, 149	Rabbit's fat, 103
Aretic sperm, 162	Curua palm, 103	Mangosa, 134	Radish seed, 23
Argemone, 57	Dame's violet, 62.5	Mangosteen, 123	Ranga butter, 142
Asclepia, 112	Date kernel, 11	Manihot, 68	Rape seed, 20
Awara, 100	Deer fat, 155	Manketti nut, 81	Ravison rape, 21
Babassu, 102	Dika fat, 132	Maripa fat, 140	Red pine seed, 73
Baobab, 99	Djave butter, 108	Marotti fat, 42	Rice, 10
Bay tree, 126	Dodder, 34	Menhaden, 83	Sacha Almendras, 116
Beechnut, 40	Doegling, 162	Mexican poppy seed, 57	Safflower, 59
Beef tallow, 151	Dogfish liver, 94	M'kani fat, 98	Sardine, 86
Beeswax, 169	Dolphin, 88	Mocaya, 96	Sawari nut, 116
Ben, 7	Earthnut, 3	Montan wax, 166	Scotch pine, 80
Bicuhybao, 138	Garden cress, 43	Montanin wax, 166	Seal, 92
Black mustard seed, 25	Garden rocket, 62.5	Mowrah butter, 106	Sedge, 5.5
Black walnut, 64	Gerard's pine (Himalayas), 75	Mutton fat, 152	Sesame, 47
Bone fat, 160	German sesame, 34	Myrtle wax, 135	Shark, 93, 94.5
Borneo tallow, 125	Ghee, 161	Ncat's foot, 31	Shea butter, 111
Bottlenose, 162	Goa butter, 123	Necm, 134	Shiromoji, 129
Brazil nut, 33	Goat's butter, 154	Niam fat, 130	Silver fir (Mid. Europe), 78
"Brown oil" (California), 76	Goose fat, 153	Niger seed, 61	Soya, 48
Butter fat, 161	Grape seed, 28	Njave butter, 108	Sperm, 163
Cacao, 147	Grey pine (California), 76	Nutmeg, 132	Spermaceti, 172
Cameline, 34	Hazelnut, 5	Oats, 32	Spruce, European, 73
Canari, 114	Hemp seed, 58	Oiticica, 60	Stearine, 124
Candellila wax, 165	Herring, 85	Olive, 8	Stillingia, 82, 146
Candlenut, 54, 56	Horse fat, 156	Olive kernel, 9	Stillingia tallow, 146
Cantaloup seed, 37.5	Illipe butter, 105	Orange pip, 35.5	Stone pine (S. Europe, S. Africa), 78
Cardamom, 42	Indian beeswax, 168	Otoba butter, 137	Strophantus seed, 16.6
Carnauba wax, 164	Indian mustard seed, 19	Owala, 141	Sunflower, 62
Carthamus, 59	Indian rape, 22	Palm, 119	Swiss pine, 74
Cashew nut, 2	Japan wax, 144	Palm kernel, 120, 122	Tallow, 30, 159
Castor, 27	Japanese sardine, 87	Palm pulp oil, 121	Tallow oleine, 30
Cedar nut, 74	Java almond, 114	Paradise nut, 6	Tama fat, 142
Chaulmoogra, 49	Kapok, 39	Para rubber seed, 63	Tea seed, 17
Cherry kernel, 15	Karite butter, 111	Peach kernel, 1	Teglam fat, 125
Chicken fat, 157	Katio, 107	Peanut, 3	Tomato, 44
China wood, 53, 55	Kokum butter, 123	Pecan, 64	Tung, 52, 53, 55, 70
Chinese insect wax, 171	Kuromoji, 128	Perilla, 71	Ucuhuba fat, 138
Chinese vegetable tallow, 146	Lallemantia, 63	Phulwa butter, 104	Ungnadia, 18
Chironji fat, 110	Lard, 29, 150	Physic nut, 26	Veppam fat, 134
Chrysalis, 95	Lard oleine, 29	Pilehard, 86	Walnut, 65
Coal fish, 90	Laurel butter, 126	Pili nut, 115	Whale, 84
Coconut, 117	Lemon pip, 36	Pimento seed, 72	Wheat, 50
Cod liver, 91	Linseed, 67	Piney tallow, 149	White mustard seed, 24
Cohune nut, 101	Luffa seed, 43.5	Piririma, 118	Wild mango, 132
Colza, 20	Lumbang, 54	Pistachio nut, 12	Wool fat, 167

## French

(Dans la table suivante, le mot "huile" n'est pas mentionné. Les diverses références sont des huiles à moins qu'elles ne soient spécifiées comme "graisses" "cires," etc.)

Abeille chinoise, 170	Baleine, 84	Chênevis, 58	Ghé, 161
Abeille commune, 169	Bancoulier, 52, 53, 54, 55, 56	Chrysalide du bombyx, 95	Gland, 46
Abeille des Indes, 168	Baobab, 99	Cire de montagne, 166	Graisse de boeuf, 30, 151
Aiguillat, 94	Ben, 7	Cirier, 135	Graisse de cheval, 156
Akébie, 97	Beurre, 161	Cocotier, 118	Graisse de laine, 167
Alose, 83	Beurre de Galam, 111	Colza, 20	Graisse de lapin, 158
Amande, 13	Beurre de lait de chèvre, 154	Coton, 41, 124	Graisse de mouton, 152
Andiroba, 4	Beurre de Tama, 142	Cresson alénois, 43	Graisse d'oie, 153
Anthelmintique, 42	Cacao, 147	Croton, 37	Graisse d'os, 160
Arachide, 3	Cameline, 34	Dauphin, 88	Graisse de poulet, 157
Argémone du Mexique, 57	Canarium de Java, 114	Epicéa, 73	Grand requin, 94
Arolle, 74	Carapa, 4	Euphorbe antisyphilitique, 105	Hareng, 85
Avoine, 32	Carthame, 59	Faine, 40	Hevea, 63
Azédarac, 134	Cerf commun, 155	Foie de morue, 91	Hyperodon à rostre, 162
Babassu, 102	Chaulmoogra, 49	Froment, 50	Julienne, 62.5



Kapock, 39	Noix d'Amérique, 64	Pépins de melon, 37.5	Roquette, 22
Lard, 29	Noix du Brésil, 33	Pépins d'orange, 35.5	Saindoux, 150
Laurelle, 126	Noix de coco, 117	Pépins de raisin, 28	Sapin blanc, 78
Lin, 67	Noyaux d'abricot, 14	Perilla, 71	Sapin rouge, 73
Madar, 112	Noyaux de cerises, 15	Phoques divers, 92	Sardine, 86
Maïs, 51	Noyaux de datte, 11	Pied de boeuf, 31	Sardine japonaise, 37
Mangue, 132	Noyaux d'olive, 9	Pignon, 79	Sénévé blanc, 24
Manihot, 68	Noyaux de pêches, 1	Piment, 72	Sénévé noir, 25
Manioc, 68	Noyaux de prunes, 16	Pin de montagne, 77	Sésame, 47
Marsouin, 89	Oeillette, 69	Pin silvestre, 80	Souchet, 5.5
Merlan, 90	Olive, 8	Pistache, 12	Soya, 48
Moutarde indienne, 19	Palme, 120, 121, 122	Puceron, 171	Spermaceti, 172
Moutarde noire, 25	Palmier africain, 119	Radis, 23	Sperme du cachalot, 163
Mudar, 112	Palmier américain, 164	Requin de Japon, 94.5	Strophante, 16.6
Muscade, 136, 137, 138	Passerage, 43	Requin petit, 93	Suif, 159
Navette, 21	Paulonia, 70	Ricin, 27	Suif végétal, 82
Noisette, 5	Pavot, 69	Ricin infernal, 26	Sumac, 144
Noix, 65	Pépins de citron, 36	Riz, 10	Tomate, 44
Noix d'acajou, 2	Pépins de courge, 38	Riz de veau végétal, 109	Tournesol, 62

## German

(In dem folgenden Index wird das Wort "Öl" meistens ausgelassen. Die verschiedenen Bezeichnungen gelten Ölen, wenn sie nicht besonders mit den Namen "Fette," "Wachse," etc. bezeichnet sind)

Afrikanischer Butterbaum, 142	Gänsefett, 153	Mandel, 13	Rotraps, 62.5
Afrikanischer Ölbaum, 119	Gartenkresse, 43	Mankettinuss, 81	Rübe, 20
Akebia, 97	Goabutter, 123	Meerschwein, 89	Rucka, 22
Ahorn, 46	Häring, 85	Melone, 37.5	Safflor, 59
Amerikanische Nuss, 64	Hafer, 32	Menhaden, 83	Sardine, 86
Aprikosenkern, 14	Haifisch, 93, 94.5	Mexikanischer Mohnsamen, 57	Sardine japanische, 87
Arachis, 3	Hanf, 58	Mohn, 69	Schaffsfett, 152
Asnaröl, 100	Haselnuss, 5	Montanwachs, 166	Schwarmkürbiskern, 43.5
Bankulnuss, 54, 56	Haushühnfett, 157	Muskatnuss, 136	Schweinefett, 29, 150
Baobab, 99	Indischer-Butterbaum, 104	Muskatnuss von Santa Fe, 137	Seal, 92
Baumwolle, 124	Indisches Wachs, 168	Myrthe, 135	Senf, 19
Baumwollsaamen, 41	Jamaika-Pfeffer, 72	Ölfirnisbaum, 52, 53, 55	Senf, weiss, 24
Becuhybafett, 138	Japanwachs, 144	Ölpalme, 121	Senf, schwarz, 25
Behenöl, 7	Java Mandel, 114	Olive, 8	Sesam, 47
Bienenwachs, 169	Kakao, 147	Olivenkern, 9	Shiromoji, 129
Bongoschmalz, 130	Kandellila Wachs, 135	Orangensamen, 35.5	Silberföhre, 78
Buchnuss, 40	Kaninchenfett, 158	Otobafett, 137	Sonnenblume, 62
Butter, 161	Kapok, 39	Palmkern, 120, 122	Soyabohne, 48
Candlenuss, 54, 56	Karnauba Wachs, 164	Paradisnuss, 6	Steinfente, 79
Carapa, 4	Kirschenkern, 15	Parakautschuk, 68	Stillingiatalg, 146
Cedernuss, 74	Knochenfett, 160	Parakautschukbaumsamen, 63	Strophantus, 16.6
Chaulmoogra, 49	Kohl, 21	Paranuss, 33	Talg, 30, 159
Chaulnegraöl, 42	Kokosnuss, 117	Paulownia, 70	Teglamfett, 125
Chinesischer Talg, 82	Kongo Akazie, 141	Peki, 116	Tomaten, 44
Chinesisches Wachs, 170	Kopalbaum, 149	Perilla, 71	Tuajapalme, 133
Citronenkern, 36	Korungöl, 143	Pferdefett, 156	Traubensamen, 28
Cohune, 101	Kroton, 37	Pärsiehkern, 1	Ungnadia, 18
Colza, 20	Kürbis, 38	Pflaumenkern, 16	Wachsbaum, 144
Coumöl, 139	Kuromoji, 128	Pistazi, 12	Walfisch, 84
Curcas, 26	Legföhre, 77	Pottwal, 163	Walnuss, 64
Dattelkern, 11	Leindotter, 34	Puppe, 95	Walrat, 172
Dintennuss, 2	Leinsamen, 67	Radischen, 23	Weizen, 50
Dolphin, 88	Lorbeer, 126	Reis, 10	Wildfett, 155
Dorsch, 91	Macaja, 96	Ricinus, 27	Wollfett, 167
Dorschleber, 94	Macasar, 145	Rinderklauen, 31	Yereum, 112
Erdmandel, 5.5	Madinöl, 45	Rindertalg, 151	Zedrach, 134
Erdnuss, 3	Mafura Talg, 131	Rosfichtensamen, 73	Ziegenbutter, 154
Feldkohl, 20	Mahuabutter, 105	Rotföhre, 80	
Fulwabutter, 161	Mais, 51		

## Italian

(Nell'indice seguente è stata omessa la parola "olio." I diversi prodotti sono olii, tranne che non sia esplicitamente dichiarato che si tratta di "grassi," "cere," ecc.)

Abete, 73	Albero del sego, 82	Avena, 32	Burro di Ghee, 161
Abete rosso, 78	Albicocche, 14	Balena, 84	Burro di Illipè, 105
Agretto, 43	Alloro, 126	Bangu, 35	Burro di Karité, 111
Akebia, 97	Ape cinese, 170	Baobab, 99	Burro di Niave, 108
Akee, 109	Ape indiana, 168	Basilico della Cina, 71	Cacao, 147, 148
Akoon, 112	Arachide, 3	Bene, 7	Camellina, 34
Albero da burro indiano, 104	Aringa, 85	Bombice del gelso, 95	Canapa, 58
Albero di caucciù, 63	Asclepia, 112	Burro, 161	Capodoglio, 163
Albero della cera, 135	Astrocario, 100	Burro di Diave, 108	Carapa, 4

Cardamomo, 42  
 Combro, 74  
 Cera carnauba, 164  
 Cera gialla, 169  
 Cera del Giappone, 144  
 Cera di mirica, 135  
 Cera montana, 166  
 Cipero commestibile, 5.5  
 Chaulmagra, 42  
 Chiura, 104  
 Cocciniglia della cera, 171  
 Colza, 20  
 Comore, 139  
 Cotone, 41, 124  
 Crescione inglese, 43  
 Crotoniglio, 37  
 Delfino dal rostro, 162  
 Dorella, 34  
 Essenza di Kuromoji, 128  
 Faggiola, 40  
 Fegato di merluzzo, 91  
 Fibre di Piassava, 102  
 Focena, 89  
 Frumento, 50  
 Garcinia, 123  
 Girasole, 62  
 Globicefalo, 88  
 Gomma elastica ceara, 68  
 Grano, 50  
 Granone, 51  
 Granoturco, 51  
 Grasso di anitra domestica, 153  
 Grasso di Bonantjo, 98  
 Grasso di Borneo, 125  
 Grasso di bue, 30  
 Grasso di capra, 154  
 Grasso di cavallo, 156  
 Grasso di cervo, 155  
 Grasso di Chironji, 110  
 Grasso di Cohune, 101  
 Grasso di cokerite, 133  
 Grasso di coniglio, 158  
 Grasso di Katian, 107

Grasso di Kobi, 4  
 Grasso di lana, 167  
 Grasso di Mafura, 131  
 Grasso di Maratty, 42  
 Grasso di Mené, 130  
 Grasso di montone, 152  
 Grasso di Morrah, 106  
 Grasso di Niam, 130  
 Grasso di ossa, 160  
 Grasso di pollo, 157  
 Grasso di Pongamia, 143  
 Grasso di Sawari, 116  
 Grasso di Taccamaca, 113  
 Grasso di Tama, 142  
 Grasso di Teglam, 125  
 Grasso di Teomaica, 113  
 Hesperide, 62.5  
 Iperodonte, 162  
 Jatrofa, 26  
 Kapok, 39  
 Lallemanzia, 66  
 Lana vegetale, 39  
 Lardo, 29, 150  
 Lauro, 126  
 Lauro greco, 134  
 Legno della China, 53, 55  
 Legno del Giappone, 52  
 Lino, 67  
 Luffa, 43.5  
 Macassar, 145  
 Madia, 45  
 Mandorle, 13  
 Mandorle di Giava, 114  
 Mandorle di pesco, 1  
 Mango, 132  
 Manihot, 68  
 Maripa, 103, 140  
 Melia, 134  
 Mellone, 37.5  
 Merlango, 90  
 Miagro falso, 34  
 Mocaja, 96  
 Nasturzio, 43

Noccioli di acagiù, 2  
 Noccioli di cilegia, 15  
 Noccioli di dattero, 11  
 Noccioli d'oliva, 9  
 Noccioli di palma, 120, 122  
 Noccioli di prugne, 16  
 Nocciuola americana, 3  
 Nocciuole, 5  
 Noce americana, 64  
 Noce di Bankul, 54, 56  
 Noce del Brasile, 33  
 Noce di cocco, 117  
 Noce moscata, 136  
 Noce moscata di Santa Fè, 137  
 Noce nostrale, 65  
 Noce di Para, 33  
 Noci di Maringa, 7  
 Noci del Paradiso, 6  
 Noci di Sapucaia, 6  
 Noci di Soccari, 116  
 Oliva, 8  
 Owala, 141  
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 Papavero messicano, 57  
 Paulonia, 70  
 Patava, 139  
 Pepe della Giamaica, 72  
 Pesceccane, 93, 94.5  
 Pianta del sego, 146  
 Piede di bove, 31  
 Pimento, 72  
 Pino di California, 76  
 Pino cembro, 74  
 Pino domestico, 79  
 Pino dell' Imalaia, 75  
 Pino montano, 77  
 Pino ad ombrello, 79  
 Pino da pinoli, 79  
 Pino di Scozia, 80  
 Pino selvatico, 80  
 Pistacchio, 12  
 Pomodoro, 44  
 Popone, 37.5

Porco marino, 89  
 Quercia, 46  
 Rafano, 23  
 Ravizzone, 20, 21  
 Ricino, 27  
 Ricinodendro, 81  
 Riso, 10  
 Ruchetta, 22  
 Sardina comune, 8  
 Sardina giapponese, 87  
 Sego, 159  
 Sego di palma, 103  
 Sego di Ucuhuba, 138  
 Semi di Aburacan, 127  
 Semi di arancia, 35.5  
 Semi di Guizotia, 61  
 Semi di limone, 36  
 Semi del Niger, 61  
 Semi di papavero, 69  
 Semi di strofanto, 16.6  
 Senapa bianca, 24  
 Senapa indiana, 19  
 Senapa nera, 25  
 Sesamo, 47  
 Sevo di bue, 151  
 Sevo di Malabar, 149  
 Sevo di Piney, 149  
 Shiromoji, 129  
 Sicomoro falso, 134  
 Soja, 48  
 Spermaceti, 172  
 Spinarolo imperiale, 94  
 Stillingia, 82  
 Strutto, 29  
 Sugna, 29  
 Ungnadia, 18  
 Vinaccioli, 28  
 Vitello marino, 92  
 Zafferano falso, 59  
 Zafferanone, 59  
 Zucca, 38



## 2. SCIENTIFIC NAMES AND COMMON PROPERTIES

## Non-drying Vegetable Oils of the Olive Oil Type

F = fruit pulp; G = whole grain; Gm = germ; K = kernel; N = nut; S = seed; R = rhizome; n = refractive index

General Index No.	Scientific name and source	Density $d_{15}^{15}$	Congelation temperature °C	Acid value v. p. viii	Saponifica- tion value v. p. viii	Iodine value v. p. viii	Acetyl value v. p. viii	Hehner value v. p. viii	Reichert- Meissl value v. p. viii	Unsapon- ifiables %	Fatty acids M. P. °C	"Titer" test °C v. p. viii	<sup>n</sup> Finding No. v. p. 212
0.5	<i>Abelmoschus moschatus</i> (S).....	0.917-0.918			195	95	6.5	96		0.3		13-13.5	69
1	<i>Amygdalus Persica</i> (S).....	0.918-0.925	-20	1-1.5	191-193	92-99.7		94-96					61
2	<i>Anacardium occidentale</i> (S).....	0.918		1.45	194-200	79.5	3.5	95	0.6	1.5		30.5-39	66
3	<i>Arachis hypogaea</i> (S).....	0.917-0.926	3	0.8	186-194	88-98		93-96	0.4	0.5-0.9	21-30		
3.5	<i>Camellia oleifera</i> (S).....	0.916-0.927	-12		180-196	80-90		92-93.7	0.8-1		38.8		43
4	<i>Carapa Guianensis</i> (S).....	0.912-0.923	4.5		188-195.6	58-65		95.5	2.5-3.3	0.5	22-25	19-20	52
5	<i>Corylus avellana</i> (S).....	0.917	-17 to -18		191-197	87	3.2		0.99				77
5.5	<i>Cyperus esculentus</i> (R).....	0.924	below 0		225	62-76					37.6		60
6	<i>Leceythis zabucajo</i> (S).....	0.895	4	3.19	173.6	76.6	44.8	95	0.5			37.8	63
7	<i>Moringa oleifera</i> (S).....	0.912-0.920	7-8		185-189	109-112.6		95					65
8	<i>Olea Europaea sativa</i> (F).....	0.915-0.920	{ +2 turbid -6 deposit }	0.3-1.0	185-196	79-88	10.5	95	0.6-1.5	0.4-1.0	26-30	16.9-26.4	85
9	<i>Olea Europaea sativa</i> (S).....	0.918-0.919	-10	1-1.8	182-186	88		95.2		3			37
10	<i>Oriza sativa</i> (S).....	0.920-0.927	18.1	43-77.2	192-195.8	96.4-99.9		95.2	0.88				57
11	<i>Phoenix dactylifera</i> (S).....		-5 to -10		211	52.3		96			17-20	13-14	58
12	<i>Pistacia vera</i> (S).....	0.913-0.919	-15 to -20	0.5-3.5	183.3-207.6	93-103.4	9.6	96.0	0.5	0.75	13-14	9.5-11.8	70
13	<i>Prunus amygdalus</i> (S).....	0.914-0.921	-17	3.5	191.4-198.2	100-108.7	12.2		0.2		2.3-4.5		38
14	<i>Prunus Armeniaca</i> (S).....	0.915-0.926	-19 to -20	1.1	193.3-195	110-114.3					19-21	13-15	
15	<i>Prunus cerasus</i> (S).....	0.918-0.929	-5 to -8	0.55	191-193	100-103.6		95-96	1.0		12.4-18	31-32	68
16	<i>Prunus domestica</i> and <i>P. damascena</i> (S).....	0.912-0.913	-6		188-199	76-83		92-95	0.5-0.9		32.2		81.5
16.5	<i>Sterculia foetida</i> (F, S).....	0.926	3-4		188-195	96-102		91-92			42-44		48.5
16.6	<i>Strophanthus hispidus</i> (S).....	0.9249-0.9254	-12		175-196	84-89		91.5	0.1				54.55
16.7	<i>Terminalia catappa</i> (S).....	0.917-0.920			190-194	91		94			19	10	
17	<i>Thea sasanqua</i> (S).....	0.920			191-192	81-82							
18	<i>Ungnadia spectiosa</i> (S).....	0.912											

## Non-drying Vegetable Oils of the Rape Oil Type

19	<i>Brassica juncea</i> (S).....	0.916-0.921	-10	3.7-7.2	172-180	102-108	14.75	95.5	0.33-0.89	1.48	18.5-20	11.7-13.6	78
20	<i>Brassica campestris</i> (S).....	0.913-0.917	-8	0.30-1.0	168-179	94-105		94.5-96.3	0-0.79	1.4-1.7		13.5-16.5	82
21	<i>Brassica</i> (varieties of) (S).....	0.916-0.919			177-181	109-122							94
22	<i>Eruca sativa</i> (S).....	0.916-0.919	-10 to -18	2.5-3.7	169-174	97.5-102		95.5	0.75		20	13-15	80
23	<i>Raphanus sativa</i> (S).....	0.916-0.918	-8 to -16	5.4	174-178	94-98.4		95.9	0.33		15-16		71
24	<i>Sinapis alba</i> (S).....	0.912-0.916		5.7-7.3	171-174	99-110		96-97		3.3	16-17	13.4-13.7	75
25	<i>Sinapis nigra</i> (S).....	0.915-0.919			173-175	115-120		96					88
25.1	<i>Sinapis nigra</i> (Russian).....	0.920			181-182								

## Non-drying Vegetable Oils of the Castor Oil Type

26	<i>Jatropha curcas</i> (S).....	0.919-0.924	{ 4.4 turbid 2.8-2.9 solid }	0.5-5.0	192.5-210	98-110	9-25.3	95.2	0.28-0.48		24-30		67
27	<i>Ricinus communis</i> (S).....	0.960-0.967	{ -12 turbid -17 to -18 solid }	0.12-0.8	175-183	84	146-150.5		1.4	0.6	13		110
28	<i>Vites vinifera</i> (S).....	0.917-0.933	-10 to -17	0.75	171-191	94.3-135	13.5-14.5	92	0.46	1.6	23-25		89

## Non-drying Animal Oils

L = lard; T = tallow; F = foot

29	<i>Oleum adipis</i> (L).....	0.913-0.915	-2 to +4	{ 1.56 (0.1-2.5) }	193-198	62.5-79		97		0.6	33-38.4	27-33	45
30	<i>Oleum adipis bovis</i> (T).....	0.914-0.919	2 to 7.5	0.2-0.25	193.5-199	56-60.5						35-37.5	
31	<i>Oleum padis bovis</i> (F).....	0.913-0.918	-2 to +10	0.1-0.6	193-199	57.5-75	7.7-9.3	94.8-95.9	0.9-1.2	0.12-0.65	29-41	16-26.5	47

## Vegetable Semi-drying Oils

F = fruit pulp; G = whole grain; Gm = germ; K = kernel; N = nut; S = seed

32	<i>Avena sativa</i> (G).....	0.925	0 to 3	34.7-35.3	189.8-192.4	114.2		94.9		1.30-2.65	27.5		114
33	<i>Bertholletia excelsis</i> (K).....	0.917-0.918	-18	1.4	193	90-106					28-30	31.1-32.2	56
34	<i>Camelina sativa</i> ( <i>Myagrum sativa</i> ) (S).....	0.923-0.927			188	132-152					13-14	17-18	107

## Vegetable Semi-drying Oils.—(Continued)

General Index No.	Scientific name and source	Density $d_{15}^{25}$	Congelation temperature °C	Acid value v. p. viii	Saponification value v. p. viii	Iodine value v. p. viii	Acetyl value v. p. viii	Hehner value v. p. viii	Reichert-Meissl value v. p. viii	Unsaponifiables %	Fatty acids M. P. °C	"Titer" test °C v. p. viii	$\eta$ Finding No. v. p. 212
35	<i>Ceratoltheca sesamoides</i> (S).....	0.916		0.63	190.2	110.6							83
35.5	<i>Citrus aurantium</i> (S).....	0.918-0.919			194-197	97-104		95-96	0.5-0.8			19.7-21.0	70.5
36	<i>Citrus limonum</i> (S).....	0.916-0.918	-6		188.3	107.3	13.6	95.6	0.55			17-19	115
37	<i>Croton tiglium</i> (S).....	0.942-0.944	-8 to -18	27-30.9	193-215	108-109	19.8-38.6			1.1			
37.5	<i>Cucumis melo</i> (S).....	0.921 <sup>25</sup>	-15	0.43	192.3	125.9	15.8	95.1	0.33			26-28	95
38	<i>Cucurbita pepo</i> (S).....	0.923-0.925			188-193	121-130		96	4.45		38		64
39	<i>Eriodendron anfractuosum</i> (S).....	0.923-0.933	-17	3-15	189-194.5	78-93					23-24		73
40	<i>Fagus sylvatica</i> F. <i>Americana</i> (K).....	0.922	+12 to -13	0.6-0.9	191-196	97-111	21-25	95-96	0.95	1.1	34.5		143
41	<i>Gossypium</i> species (S).....	0.917-0.918 <sup>25</sup>	24	6.7	202	94.0		95.7	1.02		55		122
41.5	<i>Hydnocarpus alcala</i> .....	0.948 <sup>30</sup>		0.6	206-209.8	84.5-90.8	21.8	95.5			46		140, 142
42	<i>Hydnocarpus anthelmintica</i> (S).....	0.949 <sup>30</sup>	23	5.3	199	83.5					43		145
42.1	<i>Hydnocarpus Hutchinsonii</i> (S).....	0.943 <sup>30</sup>	21	6.6	206	89.0					41		144
42.2	<i>Hydnocarpus subfalcata</i> (S).....	0.951 <sup>30</sup>	20	1.2	191	90.7					47		
42.3	<i>Hydnocarpus venenata</i> (S).....	0.947 <sup>30</sup>	11	6.7	207	97.0					40		
42.4	<i>Hydnocarpus Wightiana</i> (S).....	0.947 <sup>30</sup>	18	5.9	192	68.5					43		
42.5	<i>Hydnocarpus Woodii</i> (S).....		-15	28.8	180-183	102-118		95.5	0.2-0.4		16-18		86.5
43	<i>Lepidium sativum</i> (S).....	0.920-0.924			188	108.5		95	1.4				97
43.5	<i>Luffa Egyptica</i> (S).....	0.9254			187-192	107-125	11.4-20.5	95-96.6	0.1-0.3				
44	<i>Lycopersicum esculentum</i> (S).....	0.922	-10 to -12		193-194	121-129		95.5			21.7	22-26	137
45	<i>Madia sativa</i> (S).....	0.921-0.933	7	6.9	200	78.5					18		
45.1	<i>Pangium edule</i> (S).....	0.925 <sup>30</sup>	-10		199.3	100.0					25		
46	<i>Quercus agrifolia</i> (S).....	0.916	-4 to -6	9.8	188-193	103-117		95	1.1-1.2		25-35	23-32	87
47	<i>Sesamum indicum</i> (S).....	0.919 <sup>25</sup>	-10 to -16	0.3-1.8	189-193.5	122-134	4.9	93-94.5	0.5-2.8	1.27-1.54	26.2-		96
48	<i>Sofa hispida</i> ( <i>Dolichos hispida</i> ) (S)	0.924-0.927	20-25		196-213	97.6-110.4					27.5		130
49*	<i>Taractogenos Kurzii</i> (S).....	0.943-0.954	0 Viscous	1.37-2.02	183-190	115					39-40		100
50	<i>Triticum sativum</i> (Gm).....	0.924-0.929	-10 to -20		187-193	111-128	7.5-11.5	93-95	4.3	2.4-2.6	17-20	14-16	86
51	<i>Zea mais</i> (S).....	0.921-0.928											

## Vegetable Drying Oils

52	<i>Aleurites cordata</i> (S).....	0.934-0.940	3		194-197	150-158			0.39	0.4-0.8	30-49	36-39	149
53	<i>Aleurites Fordii</i> (S).....	0.939-0.949	2		190-197	163-171			1.10	0.4-0.8			149
54	<i>Aleurites moluccana</i> (S).....	0.925	2		189-195	163-164	9.8	95-96	1.2	0.5-0.9			111
55	<i>Aleurites montana</i> (S).....	0.939-0.949	2		190-197	163-171			0.35	0.4-0.8			149
56	<i>Aleurites triloba</i> (S).....	0.927			202-204	139-143.8						17.8	111
56.5	<i>Amora rohituka</i> (S).....	0.931-0.939	17.0		190-192	135		93.2	1.6		20-22	16-14	105.5
57	<i>Argemone Mexicana</i> (S).....	0.925	6.0		188-190	120-122.5		95.1	0.0	1.14	22.8		91
58	<i>Cannabis sativa</i> (S).....	0.928-0.934	0.45		190-195	145-161.7				1.08	17-21	15.6-16.6	126
59	<i>Carthamus tinctorius</i> (S).....	0.925-0.928	0.6		188-203	122-141	16.1	95	0-0.2		11-17	7-12	102
60	<i>Conepis grandifolia</i> (S).....	0.969	5.7		188.6	179.5					21.5		148
											(begins)		
											65.0		
											(ends)		
61	<i>Guizotia oleifera</i> (S).....	0.925-0.927	-8	0.95-2.94	189-192	126.4-133.8		95.4	0.5	0.31	22-24	22.6	108
62	<i>Helianthus annuus</i> (S).....	0.924-0.926	-17		188-193	129-136					25.4	18-19.8	
62.5	<i>Hesperis matronalis</i> (S).....	0.931-0.934	-22		192	155							
63	<i>Hevea Brasiliensis</i> (S).....	0.924-0.930	-12 turbid	8.6-9.0	190-200	117-140	28	95.3	0.27-0.3		0	15-20	93
64	<i>Juglans nigra</i> (N).....	0.918-0.921		2.5	190.1-191.5	141-142.7		95.8					
65	<i>Juglans regia</i> (N).....	0.925-0.927	-25		190.1-197	139-150		93.4-95.4	0.92		15-20	14.3	113
66	<i>Lallemantia iberica</i> (S).....	0.933 <sup>30</sup>	-19 to -27	1-3.5	185	162		94.5-95.5	0.95		22.2	16-20.6	127, 128
67	<i>Linum usitatissimum</i> (S).....	0.930-0.938	-17	12.1	188-195	175-202	21	94-96	0.4-3.0		20-24	20-24	90
68	<i>Manihot glaziovii</i> and <i>M. ceara</i> (S).....	0.924-0.932			188-192	117-139					23-26		
68.5	<i>Oncoba spinosa</i> (S).....	0.930			192.2	177.0				1.3			125

\* *Oleum Chaulmoograe* (U.S.P.X.):  $d_{25}^{25}$ , ca. 0.950; congeals below ca. 25°; sapon. value, 196-213; I value, 98-104;  $[\alpha]_D^{25}$  48-60°.



## Vegetable Drying Oils.—(Continued)

General Index No.	Scientific name and source	Density $d_{15}^{15}$	Congelation temperature °C	Acid value v. p. viii	Saponification value v. p. viii	Iodine value v. p. viii	Acetyl value v. p. viii	Hegner value v. p. viii	Reichert-Meissl value v. p. viii	Unsaponifiables %	Fatty acids M. P. °C	"Titer" test °C v. p. viii	<sup>n</sup> Finding No. v. p. 212
69	<i>Papaver somniferum</i> (S).....	0.924-0.926	-16 to -18	2.5	193-195	128-141		95.4	0.6	0.43	20.5	17-19	106
70	<i>Paulownia imperialis</i> (S).....	0.935-0.940	below -17		193.4-196.3	149-158							150
71	<i>Perilla ocimoides</i> (S).....	0.930-0.937			188-194	185-206		95.8			-5		133
72	<i>Pimento officinalis</i> (S).....	0.923 <sup>20</sup> <sub>30</sub>		0.03	171.4	134.4							
73	<i>Pinus abies</i> (S).....	0.931	-26		192	120.5							101
74	<i>Pinus cembra</i> (S).....	0.930-0.932	-20	1.5	191.8	150-159.2			2.0	1.3	0		116
75	<i>Pinus Gerardiana</i> (S).....	0.931	-17		191-192	118-119		93.27			19		72
76	<i>Pinus monophylla</i> (S).....	0.933			189-192.8	101.3-108		92			0		
77	<i>Pinus montana</i> (S).....	0.932	-25		180-190	145-146					16-19	10-16	146
78	<i>Pinus pecea</i> (S).....	0.921	-18 to -20		191-193	119-120		91-92				10-15	98
79	<i>Pinus pinea</i> (S).....	0.928-0.933	-27		189.8	147.1							10
80	<i>Pinus sylvestris</i> (S).....	0.932	-28 to -29		190-195	124-135		94-98	0.75		30-40		147
81	<i>Ricinodendron Rautanenii</i> (S).....	0.928-0.930	-12 to -22		209-210.4	145-161	28.7	94.4-95.2	0.93-0.99	1.45			135
82	<i>Stillingia sebifera</i> (S).....	0.940-0.946		1.24									

## Fish and Marine Animal Oils

F = whole fish; B = blubber; L = liver													
83	<i>Alosa menhaden</i> ( <i>Brenortia tyrannus</i> ) (F).....	0.923-0.933	-5		180-192.9	148-185			1.2	0.6-1.43			123
84	<i>Balaena mysticetus</i> and other species (B).....	0.917-0.924	0 to -2	1.9	160-202	90-146	11-23	93-95	14	1-4	14-27	10-24	103
85	<i>Clupea harengus</i> (F).....	0.920-0.939			170-194	102-149		95-96		1-2	30-32		112
86	<i>Clupea pilchardus</i> , <i>C. scombrinus</i> (F).....	0.920-0.934	20-22		187.7-196	150-193	21-22	93.3-96	0.5-1	0.98	30-34.8	28.2	134
87	<i>Clu panodon melanostica</i> (F).....	0.928-0.935		2.2	189-192.1	121.5-124.5		94.5-97		0.5-3	35-36	27.6-28.2	76
88	<i>Delphinus globiceps</i> (B).....	0.908-0.930	+5 to -3		187.3	99.5		93.1	5.6	2			26, 49
89	<i>Delphinus phocaena</i> (B).....	0.926			290 (Jaw)	32.8 (J)		65.9 (J)					32
90	<i>Gadus merlangus</i> (L).....	0.925-0.930			203.4 (Body)	126.9 (Bo)		68.4-	46.9 (Bo)	16-17			
91	<i>Gadus morhua</i> (L).....	0.922-0.931	-3	5.6	253.7-272.3 (J)	30.9-49.6 (J)		72.0 (J)					
92	<i>Phoca species</i> (B).....	0.915-0.926	3		177-189	123-181	1.15	95	0.4-0.7	0.7-7	31	17.5-24.3	118
93	<i>Selache (cetorhinus) maxima et al.</i> (L)	0.916-0.919			171-189	137-166		95.3	0.2	0.54-2.68	21.8-38		109
94	<i>Squalus acanthias</i> (L).....	0.918			187.5-196.2	130-172	11.9	93-96	0.2	0.3-1.0	22-23		119, 121
94.5	Various species Japanese sharks (L)*.....			0.0-4.3	157-164	115-139		87-97		2.8-15.2	21-22		92
		0.864-0.932			169.7	126.4	91-345			8.4			

\*Extremes for 36 species (188).

Japanese salmon and trout oils: see Toyama, 142, 26: 273; 23. Liver oil of palm-crab, Kobayashi, *Ibid.*, 585.

## Insect Oil

95	<i>Bombyx mori</i> (from pupae).....	0.928	0	18.6-27.5	190-194	116.3-131.9	19.7	94.5	3.4	2.61	36.5	27-28	99

## Vegetable Fats

F = fruit pulp; G = whole grain; Gm = germ; K = kernel; N = nut; S = seed

96	<i>Acrocomia sclerocarpa</i> (F & K).....	0.866 <sup>100</sup> (K)		55.8 (F) 0.4-4.7 (K)	189 (F) 237-255 (K)	77.2 (F) 16-30 (K)			5.7-7.2 (K)	20.5-21 (K)			10
97	<i>Akebia quinata</i> (S).....	0.934		25.4	246.4	78.38		85.8	39.76	31			22
98	<i>Allanblackia</i> ( <i>Stearodendron</i> ) <i>Stuhlmannii</i> (S).....	0.856-0.861 <sup>100</sup> 0.930	30.4-38	11.6-23	186.6-191.7	38.7-41.9				59	61.4-61.6		17
99	<i>Adansonia digitata</i> (S).....	0.915-0.920	+3 to -3	43.8 (F)	190-192	56-79				35-38			19, 39
100	<i>Astrocaryum vulgare</i> (S).....	0.867 <sup>100</sup> (K)	28.6 (K)	0.54-1.69 (K)	220.2 (F) 240-250 (K)	46.4 (F) 12.2-13.9 (K)			3.8 (K)	0.75 (F)	27 (K)		6
101	<i>Attalea cohune</i> (S).....	0.868-0.871 <sup>100</sup>			251	11-13.7			8		27-28		3
102	<i>Attalea funifera</i> (S).....	0.868 <sup>100</sup>	22.7	2.8	246.9	15.6-16.3			5.8				
103	<i>Attalea spectabilis</i> (S).....	0.869 <sup>100</sup>	24.6	1.2	259.5	8.9			6.3	0.36	23.6		7

Vegetable Fats.—(Continued)

General Index No.	Scientific name and source	Density $d_{15}^{15}$	Congelation temperature °C	Acid value v. p. viii	Saponification value v. p. viii	Iodine value v. p. viii	Acetyl value v. p. viii	Hehner value v. p. viii	Reichert-Meissl value v. p. viii	Unsaponifiables %	Fatty acids M. P. °C	"Titer" test °C v. p. viii	<sup>n</sup> Finding No. v. p. 212
104	<i>Bassia butyracea</i> (S).....	0.862 <sup>100</sup>	19-22		189-190.8	42.1-42.6		94.8-95.6	0.4-1.31	1.36	58.4		20
105	<i>Bassia latifolia</i> (S).....	0.858-0.862 <sup>100</sup>	36		192.2-199.9	53.4-67.8		94.7-94.9	0.44-0.88		39-45	38-40	41, 46
106	<i>Bassia longifolia</i> (S).....	0.864 <sup>100</sup>			188.4-189.8	60.4-62.4		94-95	1-2		56	38-41	50
107	<i>Bassia Mottleyana</i> (S).....	0.917		11.3	189-192	31.5		95.7	0.6-0.8	0.5			
108	<i>Bassia toxisperma</i> (S).....	0.858 <sup>100</sup>	21	9.27	180-188.6	57-65		94.5-95	1.1-2.5	3.86	49-52.8	47	53
109	<i>Blighia sapida</i> (S).....	0.916	20	20.1	194.6	49.1		93	0.9		42-46	38-40	
110	<i>Buchanania latifolia</i> (S).....	0.858 <sup>100</sup>		15	191.8-195.4	54.7-59.9		94.8-95.8	0.33				
111	<i>Butyrospermum Parkii</i> (S).....	0.859 <sup>100</sup>	25-30	2.8	178-190	54-63		93.8-95.8	1.25-1.4	5-9	52-53		81
112	<i>Calotropis gigantea</i> (S).....	0.915			196-197	84-85		95-96	0.5		33-34		62
113	<i>Calophyllum inophyllum</i> (S).....	0.905 <sup>90</sup>			194	95.5		93.6	0.38		40-42	28-29	132
114	<i>Canarium commune</i> (S).....	0.907 <sup>90</sup>			193-200	59-66	15-16	95-96	0.1	0.19		37-40	
115	<i>Canarium ovatum</i> (S).....	0.907 <sup>90</sup>		1.42	197.4	55.9							
116	<i>Caryocarpus tomentosum</i> , etc. (S)...	0.898 <sup>10</sup>	23-29		199.5	49.5	6.6	96.6	0.65		48.3-50	46-47	31
117	<i>Cocos butyracea</i> , <i>C. nucifera</i> (K)....	0.926	14-22	2.5-10.0	253.4-262	6.2-10	2.3-6.9	82.3-90.5	6.6-7.5		24-27	21.2-25.2	1
118	<i>Cocos syagras</i> (S).....	0.864-0.868 <sup>100</sup>											5
119	<i>Elaeis guineensis</i> (W. Africa) (F)...	0.924	26.8	2.9-3.2	252.5	12.5-13.4	15.7	94.5-97	0.9-1.9		50	42.5-45.5	59
120	<i>Elaeis guineensis</i> (W. Africa) (S)...	0.858 <sup>100</sup>		10	200-205	49.2-58.9							
121	<i>Elaeis guineensis</i> (S. America) (S)...	0.866-0.873 <sup>100</sup>			243-255	10.5-17.5	7.6	91-91.5	5-6.8		25-28.5	20-25.5	12
122	<i>Elaeis guineensis</i> (S. America) (F)...		21.9	29.8-20.5	197	78.1-88.3							
123	<i>Elaeis guineensis</i> (S. America) (S)...		27.4	0.55-0.33	220.2-231.4	25.5-31.6							
124	<i>Garcinia indica</i> (S).....	0.853 <sup>100</sup>		14.5-21.0	186.8-191.3	25-34.2		94.6-95.6	0.11-1.54		60-61	39.9-51	29
125	<i>Gossypium speciosum</i> (S).....	0.867-0.868 <sup>100</sup>		4-10		88.7-93.6		96.5	0.22		27-45		79
126	<i>Isophtera borneensis</i> (S).....	0.856 <sup>100</sup>		11.3	192.1	31.5		95.7	1.1	0.5	56		23
127	<i>Laurus nobilis</i> (F).....	0.880 <sup>100</sup>			198-199	68-80			1.6				124
128	<i>Lindera praeox</i> (S).....	0.935			274	20.5		89.2	1.39			13	2
129	<i>Lindera sericea</i> (S).....	0.940			255	65.3		86.2	2.53			9-10	
130	<i>Lindera triloba</i> (S).....	0.936			282	11.6		85.7	2.0		42-49	14	
131	<i>Lophira alata</i> ; <i>L. procera</i> (S).....	0.901 <sup>40</sup>			180-194.6	60-78			0.8-0.9				
132	<i>Maforeira oleifera</i> (S).....	0.859 <sup>100</sup>											
133	<i>Mangifera Jabonensis</i> (Irvingia Barteri) (S).....	0.857 <sup>100</sup>	25-37		199-221	40-47		93	1-4		51-55	48-52	4
134	<i>Maximiliana regia</i> (S).....	0.860 <sup>100</sup>	27-35	4-10	241-245	29-31		94	0.2-0.4		35		9
135	<i>Meda azadirachta</i> (S).....	0.867 <sup>100</sup>		0.33	240.9-253	13-16			3.0		24.2		51
136	<i>Myrica cerifera</i> (M. Carolinensis) (F).....	0.925	35		185.6	72.9			8.27				
137	<i>Myristica officinalis</i> (S).....	0.995	39-43		205.5-211.7	3.9-9.5		92-94	0.5		47-48		8
138	<i>Myristica otoba</i> (S).....	0.875 <sup>100</sup>											
139	<i>Myristica beccabunga</i> (S).....	0.945-0.996		17.2	154-178	20-54			1.1-4.2			37.2	117
140	<i>Oenocarpus batava</i> (F).....	0.892	32-32.5	16.8	185-199	9-10		93-94		20.4	42.5-46		40
141	<i>Oncoba echinata</i> .....	0.912	7.0	0.48	191.8	78.2				1.1			48
142	<i>Palma Maripa</i> (K).....	0.898 <sup>100</sup>	25.5-26	4.5	192.4	99.7				1.6			
143	<i>Pentaclethra macrophylla</i> (S).....	0.868 <sup>100</sup>	14		270.5	17.3		89	4-5		27-28		74
144	<i>Pentadesma butyracea</i> (S).....	0.912-0.921	8		182-186	87-101	21-37	94-96	0.6		50-57		25
145	<i>Pongamia glabra</i> (S).....	0.869 <sup>100</sup>			189-197	45-49		95	0.3		57-60		131
146	<i>Rhus succedaneum</i> (F).....	0.924-0.935 <sup>40</sup>	40.5-46	11-12	178-185	78-94	17.25-26.5	90-91	1	1.1-1.6	44-45	36-42	34
147	<i>Schleichera trijuga</i> (S).....	0.970-0.980			206.6-237.5	4.9-12.8					53-56.5		
148	<i>Stillingia sebifera</i> (S).....	0.875 <sup>100</sup>	10										
149	<i>Theobroma cacao</i> (S).....	0.924-0.942	24-34	2.4	215-230	48-55		91-91.5	9	3.1	52-55	49.7-50.7	42
150	<i>Theobroma grandiflora</i> (S).....	0.918-0.922			179-206	23-40.5		95.3	0.2-0.9		39-57	45.2-47.2	13
151	<i>Theobroma indica</i> (S).....	0.964-0.974		1.1-1.9	192.8-195	32.8-41.7	1.97	94-95	0.3-1		48-53	50.9-52.5	21
152	<i>Vateria indica</i> (S).....	0.858 <sup>100</sup>											
153	<i>Vateria indica</i> (S).....	0.852 <sup>100</sup>		44.0	187.8	44.8			0.08	0.91	56.6-57	48.1	35
154	<i>Vateria indica</i> (S).....	0.915		5.8-15.3	188.7-192	37.8-39.1		95.1-95.2	0.2-0.4				



## Animal Fats

AT = Adipose tissue

General Index No.	Scientific name and source	Density $d_{15}^{15}$	Congelation temperature °C	Acid value a. p. viii	Saponification value v. p. viii	Iodine value v. p. viii	Acetyl value v. p. viii	Hehner value v. p. viii	Reichert-Meissl value v. p. viii	Unsaponifiables %	Fatty acids M. P. °C	"Titer" test °C v. p. viii	n Finding No. v. p. 212
150	<i>Adeps</i> (AT).....	0.934-0.938 0.861 <sup>100</sup> <sub>16.6</sub>	27.1-29.9	0.5-0.8	195-203	47-66.5	2.6	93-95			37-46.6	36-42.4	24
151	<i>Adeps bonis</i> .....	0.895 0.862 <sup>98</sup> <sub>16</sub>	31-38	0.25	196-200	35.4-42.3	2.7-8.6	96-96.5			42.5-44	37.9-46.2	
152	<i>Adeps ovis</i> .....	0.937-0.953 0.858 <sup>100</sup> <sub>16.6</sub>			195-196	48-61					33.5-49	40-48.5	28
153	<i>Anser cinereus</i> .....	0.923-0.930	22-24		191-193	58-67		94.5-95.3	0.2-0.98		36.6-40	31-34	44
154	<i>Capellae lactis adeps</i> .....	0.917-0.935 <sup>37.7</sup> <sub>37.7</sub>			233-236	25-37			20.8-27.7				14
155	<i>Cervus elephas</i> , etc.....	0.962-0.967		0.8-5.3	194.5-200	26-36		95.8	0.68	0.52	50-64	46-50	84
156	<i>Equus caballus</i> .....	0.919-0.933			195-200	75-86		95-98			31.3-53.4		
157	<i>Gallus domesticus</i> (AT).....	0.924 0.906 <sup>33.7</sup> <sub>33.7</sub>	21-27		193-204.6	66-71.5	45	94.6	1.8		38-40	32-34	36
158	<i>Lepus cuniculus</i> .....	0.934-0.936 0.861 <sup>100</sup> <sub>15</sub>			190-203	70-99.8		99.5	0.7-2.8		39-50	35-41	
159	<i>Sevum</i> .....	0.925-0.950			193-198	35-45		95-96	0.5-1.0			40-50	
160	<i>Sevum ossis</i> .....				190-196	50-55	11.3	94-95	0.2-1.7		42.5-44		
161	<i>Vaccæ lactis adeps</i> .....	0.907-0.912 <sup>40</sup> <sub>15</sub>			210-230	26-28 (Extremes 19.5-49.5)	1.9-8.6	87.6-89.6	17.0-34.5		38-41	33-39	15, 27, 30

## Sperm Oil

162	<i>Hyperoodon rostratus</i> .....	0.880-0.881		0.4-0.5	123-134	80.4-82.0	4.1-6.4			36-41	10.3-10.8	8.3-8.6	11
163	<i>Physter macrocephalus</i> .....	0.878-0.884			120-137	80-84	4.5-6.4				13.4		16

## Vegetable Non-glyceridic Waxes

164	<i>Corypha cerifera</i> (exudation from leaves).....	0.995-0.999		4-8 17.0	79-84 51	13.5	55.2			54-55			104 33
165	<i>Euphorbia anti-syphilitica</i> .....												
166	Montan wax (lignite tar, lignite peat).....			73	74	16				47			

## Animal Waxes

167	<i>Adeps lanae</i> (sheep's wool).....	0.970-0.973		59.8 6-6.1	82-130 82-83	17-29 10	23			39-44	41.8		141 18
168	<i>Apis indica</i> (bees).....												18
169	<i>Apis mellifera</i> (bees).....	0.961-0.968 0.822-0.827 <sup>98</sup> <sub>16.5</sub>	60.5-62	16.8-20.6	88-96	8.8-10.7	15.2						18
170	<i>Apis</i> (Chinese bees).....			5.3-9.7	90.2-120.2								18
171	<i>Coccus cerifera</i> (insect on leaves of <i>Fraxinus chinensis</i> ).....	0.809-0.811 0.905-0.945 <sup>99</sup> <sub>16.5</sub>	80-81	63									
172	Spermaceti (oils of <i>Cetacea</i> ).....	0.806-0.812 <sup>99</sup> <sub>15.5</sub>		0.5-2.8	126-135		2.6			51.5			

## 3. COMPOSITION TABLE

(In weight %)

GENERAL  
INDEX  
NUMBER

## Class 1. Non-drying Oils of Almond and Olive Oil Type

Glycerides principally of oleic acid. Linolic acid present in small proportion

0.5. *v.* (98.5).

1. Similar to No. 13.

2. Oil from kernels is non-drying. Olein, 80.4; stearin, 17.3 (48). The oil from the pericarp is black and has high iodine value (294) (202).

3. Palmitin, stearin, arachidin, lignocerin, olein, linolin and possibly hypogaein. The mixed lignoceric and arachidic acids (Renard's "arachidic acid") vary from 4.3 to 5.4 (av. 4.8); stearic acid *ca.* 5. Unsaturated acids *ca.* 30, of which *ca.* 60% is linolic (63). Hypogaeic acid not found (164) but occurrence considered probable (78). For variations in constants *v.* (100). "Unsaturated" fatty acids 75-79.5, with iodine value, 109-126 (100).

3.5. Similar to No. 17 (185).

4. Non-drying glycerides.

5. Oleic acid, 85; palmitic, 9.4; stearic, 1; glycerol, 10.4; phytosterol, 0.5 (76).

5.5. *v.* (19, 28.5, 150).

7. Glycerides of oleic, stearic and palmitic acids, and, according to Völker, behenic acid.

8. *Ca.* 25 solid and 75 liquid glycerides, mainly olein. Linolic acid, 7; oleic, 93 (80). No stearic acid (83). A mixed glyceride (1-2%, M. P. 53-55°), probably stearic, palmitic and oleic, has been isolated (92). Ultimate composition: C, 77.2; H, 11.3; O, 11.5 (163). Highly unsaturated acids, 78-93.5, with iodine value, 89-98 (100).

9. Similar to No. 8. Solid acids, 9.7 (of which stearic, 40; palmitic, 60); liquid acids, oleic and linolic; no arachidic (110).

10. Oil from commercial rice meal contains free fatty acids, 43-77 (168). Impure fat from polishings *v.* (68).

11. The constants indicate presence of oleic and volatile insoluble fatty acids. On the border-line between oils and solid fats.

12. Largely oleic glycerides.

13. Fatty acids, mainly oleic, with *ca.* 6 linolic (63). No linolenic. Little, if any, stearic (84).14. Similar to No. 13 *cf.* (160).

15. Resembles No. 13, but has higher iodine value (110-114), indicating larger amount linolic acid. HCN present (141).

16. Similar to No. 13, but contains more linolic acid.

16.5. *v.* (32, 200).16.6. *v.* (21.1).16.7. *v.* (72).17. Very similar to No. 8. 88-93 liquid acids with iodine value 99.6-104.4 (118). This commercial oil is distinct from tea oil (*Thea sinensis*) *v.* (184).

## Class 2. Non-drying Oils of Rape Oil Class

19. Greater proportion unsaturated fatty acids than No. 20.

20. Mainly glycerides of rapic and crucic acids (159.5); linolenic acid present (63); arachidic and lignoceric acids *ca.* 1.43 (11). Yields *ca.* 1% insoluble bromide of mixed glyceride (84). "Unsaturated" acids 94-95, with iodine value, 100.5-105 (100).

21. Larger amount less saturated glycerides than No. 20.

22. Similar to No. 24.

23. Resembles No. 20, but has less drying capacity.

24. Resembles No. 20. Contains *ca.* 1.3 arachidic and lignoceric acids (11). Yields *ca.* 1.5 insoluble bromide (84).

25. Similar to No. 24. "Unsaturated" acids, 91.5-94.5, with iodine value, 103-120 (100).

## Class 3. Non-drying Oils: Castor Oil Type

26. Glycerides of hydroxylated fatty acid, not identical with ricinoleic. Liquid fatty acids, consist of equal proportions oleic and linolic (111). Solid fatty acids, *ca.* 10, of which palmitic, 80, and stearic, 20. No linolenic.

27. Largely glycerides of ricinoleic and isoricinoleic acids (79), with small amount saturated acids.

28. Palmitic, stearic, oleic and linolic acids, and hydroxy acids (*ca.* 25), not identical with ricinoleic (5).

## Class 4. Animal Oils Largely Glycerides of Oleic Acid

29. Mainly olein, with small amount linolin, palmitin, and stearin. Practically free from volatile fatty acids.

30. Glycerides of oleic with very little solid acids.

31. Resembles No. 30, but contains more saturated glycerides. Stearic 2-3; palmitic, 17-18; oleic, 74.5-76.5; glycerol, 5-10; unsaponifiables, 0.1-0.5 (54).

## Class 5. Semi-drying Oils

Glycerides of linolic acid are characteristic constituents

32. Resembles No. 51 (146).

33. Glycerides of oleic and linolic acids. Does not yield insoluble bromide.

34. Glycerides of oleic, linolic and palmitic acids, with small amount of erucic acid (141).

35. Similar to No. 47, but does not give Baudouin reaction (27). 35.5. *v.* (52, 91.5).

37. Glycerides of stearic, palmitic, myristic, lauric, caproic, butyric, and acetic acids; also tiglic and higher homologues of oleic acid, but no oleic (163).

38. Glycerides of oleic and linolic acids.

39. Glycerides of oleic and linolic acids. Slight reaction in Becchi's test and Halphen's test.

40. Olein, linolin, with small amount palmitin and stearin.

41. C, 76.4; H, 11.4; O, 12.2 (163). Glycerides of oleic and linolic acid in approx. proportion 3 to 4.5 (224). Linolic acid, 17-18 (63). Stearic acid present. Fatty acids liberated by hydrolysis in practically same proportion as in original oil (101). Unsaturated acids, 69.7-73.9, with iodine value, 144.2-148 (100).

42. Contains hydnocarpic acid, a cyclic fatty acid of general formula  $C_nH_{2n-4}O_2$  (154); with neutralization value, 222.7; specific rotation +67.70°; iodine value, 100 (33). Method of separation from chaulmoogric acid, *v.* (51).43.5. *v.* (48).

44. Glycerides of oleic, linolic, stearic and myristic acids, with 2.3 lecithin (16). Arachidic acid at least 0.4 (223).

45. Glycerides of oleic, linolic, stearic and palmitic acids.

45.2. *v.* (59.5).47. C, 75.22; H, 11.13; O, 13.65 (163). Glycerides of oleic, and linolic acids, with small amount stearic, palmitic and myristic acids. Solid fatty acids, 12-14; linolic acid, *ca.* 16 (63). Glycerides of oleic, 48.1; linolic, 36.8; palmitic, 7.7; stearic, 4.6; arachidic, 0.4; unsaponifiables, 1.7. Unsaturated acids, 80.6%, with iodine value, 129.7 (104).48. Saturated acids, *ca.* 12 (mainly stearic and palmitic); unsaturated, *ca.* 80 (linolic and oleic, with *ca.* 50 of isomer of linolic (109)). Insoluble fatty acids: palmitic, 10; stearic, 2; arachidic, 1; lignoceric, linolenic, linolic and oleic, 88 (199); *cf.* (18).

49. Glycerides of chaulmoogric, hydnocarpic, linolic and myristic acids (45). Chaulmoogric acid: neutralization value, 200-202; specific rotation, +58° to +59°; iodine value, 89.5-90.7 (33). For constants of oils from 8 authentic species of



seeds allied to chaulmoogra, *v.* (147). Also *v.* references for No. 42.

50. Contains glycerides of oleic and linolic acids.

51. Mainly glycerides of oleic and linolic acids, with small amounts palmitic, stearic, and arachidic acids (195). Saturated acids, 4.5; olein, 44.8; linolin, 48.2 (95). Unsaturated acids, 84.6–86.4, with iodine value, 140.8–142.9 (102).

#### Class 6. Drying Oils

Usually characterized by linolenic and isolinolenic acids and linolic and isomeric acids

52. Glycerides of oleic (*ca.* 25) and elaeostearic acids (isomer of linolic acid). For constants of oils from different species *v.* (138).

53. Glycerides of  $\alpha$ -elaeostearic and oleic acids [(1), p. 207].

54. Glycerides of oleic (56.9), linolic (33.4), stearic, palmitic, myristic and linolenic acids (6.5) (204). Yields *ca.* 8% insoluble bromide.

55. Glycerides of  $\beta$ -elaeostearic, oleic, and probably linolic acids (144).

56. Oleic, 57; linolic, 33.5; linolenic, 6.5; oxidised glycerides, 2.8 (203).

57. For general characteristics, *v.* (10).

58. Glycerides of linolic, 70; linolenic and isolinolenic, 15; oleic acid, 15 (224).

59. Glycerides of solid fatty acids (palmitic and stearic) *ca.* 10; liquid acids (oleic and linolic) *ca.* 90 (122).

60. For characteristics, *v.* (30).

61. Yields only small amount insoluble bromide (84).

62. Glycerides of oleic acid, 33.4; linolic, 57.5; palmitic, 3.5; stearic, 2.9; arachidic, 0.6; and lignoceric, 0.4 (99).

63. For characteristics, *v.* (29).

64. For characteristics, *v.* (108). Cross between *J. nigra* and *J. cinere* contains *ca.* 70 linolic acid glycerides, with those of stearic, oleic, and linolenic acids (65).

65. Glycerides of myristic, lauric, oleic, linolic, and linolenic acids. Liquid acids: linolic, 80; linolenic, and isolinolenic, 13; oleic, 7 (224).

66. Elaidin test indicates large proportion olein.

67. C, 78.11; H, 10.96; O, 10.93 (163). Glycerides of solid fatty acids, 10–15. Liquid acids: oleic, 15–20; linolic, 30; linolenic, 38 (62). Saturated acids: stearic, 64.4; palmitic, 20 (140). On bromination, liquid acids yield 20–25 linolenic hexabromide (84). Yields 2 insoluble mixed glycerides on bromination: (1) linolic-dilinolenic bromoglyceride, 22–25; (2) trilinolic bromoglyceride, or oleic-linolic-linolenic bromoglyceride (182). Oil contained:  $\alpha$ -linolenic acid, 21.1; isomeric linolenic, 2.7;  $\alpha$ -linolic, 17.0; hydroxy-acids, 0.5; saturated acids, 8.0; glyceryl radical, 4.1; phytosterol, 1.0; undetermined, 46.2 (55).

69. Glycerides of oleic (20); linolic (65); linolenic acids (5) (224).

70. *v.* Nos. 52, 53, 55.

71. Glycerides of oleic, linolic, linolenic, palmitic and stearic acids. Fatty acids yield 45–51 linolenic hexabromide (66). Linolenic acid yields hexabromide identical with that from No. 67 (17).

72. Unsaturated acids, 82.8, with iodine value, 157.9 (53).

73–80. For characteristics *v.* (73).

81. *v.* (74, 170).

82. For characteristics *v.* (52).

#### Class 7. Fish and Marine Animal Oils

Characterized by presence of highly unsaturated glycerides. These oils yield insoluble bromoglycerides, which blacken when heated

83. Glycerides of palmitic, 22.7; myristic, 9.2; stearic, 1.8; unsaturated acids with 18 carbon atoms, 24.9; 20 carbon atoms, 22.2; 22 carbon atoms, 20.2 (190).

84. Glycerides of fatty acids with: C<sub>14</sub>, 4.5; C<sub>16</sub> (palmitic), 11.5; palmitoleic, 17; C<sub>18</sub> (stearic), 2.5; unsaturated (mainly oleic), 36.5; C<sub>20</sub> (unsaturated), 16; C<sub>22</sub> (unsaturated), 10; C<sub>24</sub> (unsaturated), 1.5; unsaponifiables, 1.7 (136). Oil yields *ca.* 25% insoluble bromoglyceride (84). Clupanodonic octobromide (8.39%) from fatty acids.

85. Glycerides of highly unsaturated fatty acids (iodine value, 296–317) (40). Yields clupanodonic octobromide (3.8–6.5%) (183).

86. Glycerides of highly unsaturated acids. Jecoric acid, C<sub>18</sub>H<sub>30</sub>O<sub>2</sub> (isomeric with linolenic) and palmitic (13.6) (61). For characteristics of pilchard oil *v.* (119).

87. Glycerides of highly unsaturated acids 13% with iodine value 319.5 (40). From 13–14 of clupanodonic acid, C<sub>18</sub>H<sub>28</sub>O<sub>2</sub> (iodine value 344.4) in mixed fatty acids (183). Glycerides yielded 23.6 insoluble bromide (183).

88. High proportion glycerides of volatile fatty acids (139). Also esters of other alcohols. Deposits spermaceti. Isopropylacetic acid (Chevreul's "phocoenic" acid) in volatile acids (6).

89. Glycerides of highly unsaturated acids (14.3 with iodine value 285.4) (40). Valeric acid, 19.9–24 in jaw oil; 2.71 in body oil (139).

90. For characteristics *v.* (180, 181).

91. Glycerides of myristic, palmitic, stearic, oleic, erucic and unsaturated acids C<sub>16</sub>H<sub>30</sub>O<sub>2</sub> and C<sub>20</sub>H<sub>38</sub>O<sub>2</sub> (39, 40, 41). From 17–21 of highly unsaturated acids with iodine value, 324 (189). Clupanodonic acid present (189). Acid of general formula C<sub>n</sub>H<sub>2n-8</sub>O<sub>2</sub> (clupanodonic acid) isolated. Oil yields *ca.* 34–42 insoluble bromide (84).

92. Glycerides of saturated acids, 17; liquid acids (oleic and phytostoleic) 83 (128); linolic (225); highly unsaturated acids (iodine value 330), 11.96 (40). Mixed fatty acids yield 13.9–14 insoluble bromides.

93. Glycerides of highly unsaturated acids (8.57 with iodine value 312.5) (40). Yields *ca.* 22 insoluble bromide (83). Oil from certain species contains large proportion of C<sub>30</sub>H<sub>50</sub>, spinacene (43) and squalene (186). For characteristics of liver oils (Jap. sharks) *v.* (187, 188). The liver of *Cetorhinus maximus*, 41.9–55.5 unsaponifiables, mainly squalene.

94. For characteristics *v.* (180). A shark oil.

#### Class 8. Insect Oil

95. Glycerides of oleic, linolic (4.38), solid fatty acids (mainly palmitic), phytosterol (not cholesterol); glycerol, 9.42 (185). Also *v.* (127).

#### Class 9. Vegetable Fats

96. *v.* (28).

97. *v.* (131).

98. Much stearic, little palmitic acid. Mixed glyceride, oleo-distearin, isolated (86, 89).

99. *v.* (179).

100. *v.* (28).

101. *v.* (29).

102. *v.* (28).

103. *v.* (9).

104–106. *v.* (31).

107. *v.* (31, 34).

108. *v.* (31).

109. *v.* (94).

110. *v.* (48).

111. *v.* (31).

112. *v.* (52).

113. *v.* (64, 72). The crude oil contains *ca.* 3.5% resin, on removal of which a semi-drying oil containing a large amount of linolic acid is obtained. Cong. pt. *ca.* –2°, iodine value, 96.8 (169).

114. *v.* (145).  
 115. Glycerides of oleic acid, 59.6; palmitic, 38.2; and stearic, 1.8; unsaponifiables, 0.2 (201).  
 116. Solid fatty acids, mainly palmitic; liquid acids, oleic (124); *v.* (28).  
 117. Glycerides of fatty acids in approximately proportions given: caproic, 2; caprylic, 9; capric, 10; lauric, 45; myristic, 20; palmitic, 7; stearic, 5; oleic, 2 (57). For criticisms on method of alcoholysis, *v.* (59, 174). Glycerides of kernel oil: caprylic, 9.5; capric, 4.5; lauric, 51; myristic, 18.5; palmitic, 7.5; stearic, 3 (?); oleic, 5; linolic acid glycerides, 1.0 (13). Mixed glycerides isolated (24).  
 118. *v.* (28).  
 119. Palmitin, free palmitic acid, olein and small amount linolin (84).  
 120. Glycerides of caproic acid, 2; caprylic, 9; capric, 10; lauric, 45; myristic, 20; palmitic, 7; stearic, 5; oleic, 2 (58). *v.* No. 117. Mixed glycerides (5) isolated (26).  
 121-122. *v.* (28).  
 123. Mainly oleo-distearin (87); *v.* (48).  
 124. Mainly palmitin, with glycerides of oleic and linolic acids. Stearic acid, 3.3 (83).  
 125. Glycerides of stearic, palmitic and oleic acids. Oleo-distearin and oleo-dipalmitin isolated (115). For characteristics of fats from different varieties of pontianak nuts, *v.* (71). For relationship of constants, *v.* (178).  
 126. Largely laurin with glycerides of oleic and probably linolic acid; *v.* (60).  
 127-129. *v.* (192).  
 131. Solid acids, 71.4; liquid acid (oleic), 23 (141).  
 132. Glycerides of lauric, myristic and palmitic acids (121).  
 133. *v.* (28).  
 134. *v.* (126).  
 135. Glycerides of myristic, palmitic, stearic, and oleic acids. Glycerol, 13.4 (1).  
 136. Glycerides of myristic acid, 73-74; oleic, 20; butyric, 1; essential oil, 2-3 (1).  
 137. Glycerides of lauric acid, 15.1; myristic, 52.2; palmitic, 0.2; oleic, 3.9. Unsaponifiables, 20.4 (20).  
 138. Glycerides of myristic and oleic acids and an essential oil.  
 139. *v.* (28).  
 140. *v.* (72).  
 141. *v.* (196, 200).  
 142. *v.* (197).  
 143. *v.* (126).  
 144. Largely palmitic acid and its glycerides. Mixed glyceride isolated (69).  
 145. Insoluble fatty acids, including lauric and arachidic, 91 (163). Volatile acids contain butyric and acetic acids. Liquid acids, 55; unsaponifiables, 3.12 (207).  
 146. Glycerides of palmitic and oleic acids. No stearic acid (83). Oleo-dipalmitin isolated (114).  
 147. Glycerides of stearic, palmitic, oleic, and linolic acids. Stearic acid in fatty acids, 40 (83). Saturated acids, 59.7; oleic, 31.2; other acids, 6.3 (63). Mixed glycerides (113, 116). Oleic, 43-45; palmitic, 23-25; stearic, 31-33. Five mixed glycerides isolated (3).  
 149. *Ca.* 75 solid (palmitic) and 25 liquid acids (oleic) (121).

#### Class 10. Animal Fats

150. Mainly glycerides of palmitic, stearic and oleic acids, with small amounts linolic. Palmito-distearin and stearo-dipalmitin isolated (23). Stearic acid, 7-13 (83).  
 151. Mainly glycerides of palmitic, stearic, and oleic acids, with traces of linolic and linolenic acids (63). Mixed glycerides isolated include oleo-dipalmitin, stearo-dipalmitin, oleo-

palmito-stearin and palmito-distearin (23). These crystallize in different form from lard glycerides.

152. Glycerides of palmitic, stearic and oleic acids. Stearic, 0-36 (83).  
 153. Mainly triolein, with small amounts stearo-dipalmitin, palmito-diolein, and oleo-dipalmitin (4). Fatty acids contain stearic, 3.8; palmitic, 21.2; and oleic, 72.3 (25.5).  
 154. For characteristics, *v.* (117).  
 155. Glycerides of palmitic, stearic and oleic acids.  
 156. Glycerides of oleic and linolic acids, 9.9 (63). Stearic acid sometimes present (1). No linolenic (63).  
 159. *v.* Nos. 151, 152.  
 160. Glycerides of stearic acid, 19-21; palmitic, 20-21; oleic, 53-59; glycerol, 5-10; unsaponifiables, *ca.* 0.5 (54).  
 161. Glycerides of butyric, caproic, caprylic, and capric acids, 8.35; oleic, 32.5; stearic, 1.83; palmitic, 38.61; myristic, 9.89; and lauric, 2.59, with 1.83 dihydroxystearic acid (35). Stearic acid, 0-22 (137). Mixed glycerides include butyro-diolein, butyro-palmito-olein and oleo-dipalmitin (2). For particulars of *ghee*, *v.* (29.1, 29.2, 109.5, 193.5).

#### Class 11. Liquid Animal Waxes

162. Mainly various alcohols (iodine value, 64.8-65.2) in combination with fatty acids of oleic series (1).  
 163. Mainly alcohols, chiefly of ethylene series, in combination with fatty acids of oleic series. Iodine value of alcohols, 63.9-74.1 (22).

#### Class 12. Vegetable Non-glyceridic Waxes

164. Contains a hydrocarbon (M. P. 59°), an alcohol, C<sub>27</sub>H<sub>56</sub>O; myricyl alcohol, carnaubic acid, cerotic acid, and a hydroxy acid (175).  
 165. From 50-52 hydrocarbons (37).  
 166. Esters of montanic acid and unsaponifiable matter (157, 162, 212).

#### Class 13. Animal Non-glyceridic Waxes

167. Complex mixture of esters of higher alcohols; also glycerides (50, 112, 165).  
 168. Free cerotic acid and esters of alcohols (36).  
 169. Free cerotic acid, myricin, with smaller amounts free melissic acid, unsaturated fatty acids, and ceryl and other alcohols (81, 96). Free hydrocarbons, 11.0-17.5 (38).  
 170. *v.* (36).  
 171. Chiefly ceryl cerotate with small amounts of other esters.  
 172. Mainly cetin or cetyl palmitate with very small amounts of similar esters or glycerides.

#### 4. POLENSKE VALUES

General index No.	Polenske value	General index No.	Polenske value
148	0.12	133	7.0
134	0.25	120	9-10
36	0.3	116	9-12
81	0.4	102	10.2
104	0.5-0.65	96	10.2-12.6
161	1.5-3.0	103	15.6
154	4.9-8.7	117	16.8-17.8
100	5.9		

#### 5. COMPRESSIBILITY

1 megabarye<sup>-1</sup> = 10<sup>-6</sup> cm<sup>2</sup> dyne<sup>-1</sup> = 1.0133A<sub>n</sub><sup>-1</sup> = 0.0690 in.<sup>2</sup> lb.<sup>-1</sup> = 0.9807 cm<sup>2</sup> kg<sup>-1</sup>.

*t* = 14.8°C. Δ*P* = 1 to 10 atm (134)

General index No. ....	27	67	13	91	8
10 <sup>6</sup> Δ <i>V</i> / <i>V</i> Δ <i>P</i> = .....	47	52	53	53	56



**5. COMPRESSIBILITY.**—(Continued)

$t = 40^\circ$ .  $d$  = density,  $\text{g cm}^{-3}$ .  $C = \frac{10^6}{V} \frac{dV}{dP}$  per megabarye (96)

$\frac{\text{kg } P}{\text{cm}^{-2}}$	General index No. 27		General index No. 20		General index No. 163	
	Castor oil		Rape oil		Sperm oil	
	$d$	$C$	$d$	$C$	$d$	$C$
0	0.9414		0.8980		0.8660	
157.5	0.9488	50.5	0.9058	55.7	0.8746	60.8
315.0	0.9558	48.6	0.9129	52.1	0.8820	58.2
472.5	0.9625	47.0	0.9199	51.1	0.8898	56.3
630.0	0.9686	45.3	0.9270	50.5	0.8958	53.4
787.5	0.9748	44.5	0.9330	48.2	0.9124	51.5
945.0	0.9808	43.2	0.9381	46.0	0.9088	50.5
1102.5	0.9858	41.5	0.9440	44.8	0.9136	48.1
1260.0	0.9906	40.1	0.9496	43.6	0.9196	46.9
1417.5	0.9958	39.4	0.9547	42.7	0.9249	45.7
1575.0	1.0010	38.3				

**6. VISCOSITY**

Conversion factors for different viscometer degrees, *v. vol. I*, p. 32.

Change of viscosity of oils with temperature (91).

Fish oils (205).

Solutions of camphor, of ethyl alcohol and of chloroform in olive oil (35.5).

Lubricating oils (12).

$\eta$  in Poises

OILS (12, 171)

$t = 60^\circ\text{F} = 15.5^\circ\text{C}$

General index No.	$\eta_{15.5}$	General index No.	$\eta_{15.5}$
163	0.42–0.44	26	0.858–0.878
At 100°F	0.185	13	0.860
At 150°F	0.085	1	0.869
At 212°F	0.046	21	0.935
67	0.55	3	0.942–0.950
58	0.697	8	0.950–1.01
61	0.697	At 100°F	0.377
84	0.711	At 150°F	0.154
92	0.724	At 212°F	0.070
62	0.776	31	0.987–1.13
69	0.789	20	1.08–1.18
51	0.789	At 100°F	0.42–0.45
47	0.797	At 150°F	0.18–0.19
48	0.797	At 212°F	0.08–0.09
14	0.857	27	<i>v. infra</i>
41	0.82–0.994		

FATS (12, 171)

$t = 50^\circ\text{C}$

General index No.	$\eta_{50}$	General index No.	$\eta_{50}$
117	0.154	150	0.258
120	0.171	159	0.274
147	0.171	167	
105	0.175	At 150°F	1.672
119	0.198	At 212°F	0.314
160	0.256		

**Kinematic Viscosity**

$R$  = Redwood; degrees at  $70^\circ\text{F}$  = sec per 50 cc.  $\eta_{70} = (0.0026R - 1.715/R) \times d$  ( $\pm 5\%$  approx.)

General index No.	$R_{70^\circ\text{F}}$ cf. (48)	General index No.	$R_{70^\circ\text{F}}$ cf. (48)
167	212	29	
84	188	At 60°F	356–534
At 120°	71.3	52	853–1433
65	232	At 60°F	1230–2178
69	255–259	57	
59	249–294	At 100°F	1160–1190
61	263–292	117	
57	269–272	At 140°F	63.9
8	312	123	
3	350	At 140°F	101.1
22	371	106–104	
23	385	At 140°F	110.4
20	372–465	149	
24	402	At 140°F	104.0
25	425		

**DENSITY AND VISCOSITY OF CASTOR OIL (No. 27) (12, 105)**

$t, ^\circ\text{C}$	$d, \text{g cm}^{-3}$	$\eta$ , poises	$t, ^\circ\text{C}$	$d, \text{g cm}^{-3}$	$\eta$ , poises
5	0.9707	37.60	25	0.9569	6.51
6	.9700	34.475	26	.9562	6.04
7	.9693	31.56	27	.9555	5.61
8	.9686	28.90	28	.9548	5.21
9	.9679	26.45	29	.9541	4.85
10	.9672	24.18	30	.9534	4.51
11	.9665	22.075	31	.9527	4.21
12	.9659	20.075	32	.9520	3.94
13	.9652	18.25	33	.9513	3.65
14	.9645	16.61	34	.9506	3.40
15	.9638	15.14	35	.9499	3.16
16	.9631	13.805	36	.9492	2.94
17	.9624	12.65	37	.9485	2.74
18	.9617	11.625	38	.9478	2.58
19	.9610	10.71	39	.9471	2.44
20	.9603	9.86	40	.9464	2.31
21	.9596	9.06	37.8	.9473	2.729
22	.9589	8.34	65.6	.9284	0.605
23	.9583	7.67	100.0	.9050	0.169
24	.9576	7.06			

**7. VISCOSITY UNDER PRESSURE**

VALUES OF  $\eta_P/\eta_0$  at  $40^\circ\text{C}$  (98)

$P$ $\text{kg cm}^{-2}$	General index No. 20 Rape oil	General index No. 163 Sperm oil	$P$ $\text{kg cm}^{-2}$	General index No. 27 Castor oil
0	1.00	1.00	0	1.00
157.5	1.125	1.23	23.94	1.03
315.0	1.44	1.535	227.6	1.365
472.5	1.875	1.94	550.5	2.295
630.0	2.345	2.39	864.6	3.625
787.5	3.905		1164.0	5.255
866.2		3.135		
945.0	3.495			
1102.5	4.21	4.02		
1260.0				

(*v. also* Fig. 1.)

**Influence of Temperature on Viscosity under Pressure**

400  $\text{kg cm}^{-2}$  (6000 lb. in.<sup>-2</sup>) produces approx. the following % increase in viscosity: Lard (No. 150) 75% at  $25^\circ$ , 34% at  $100^\circ$ ; sperm (No. 163) 72% at  $25^\circ$ , 29% at  $100^\circ$ .

For lard oil (No. 150) the solidifying pressure at  $21^\circ$  is ca. 155  $\text{kg cm}^{-2}$  (22 800 lb. in.<sup>-2</sup>) and at  $100^\circ$  the viscosity is increased 240% by 1500  $\text{kg cm}^{-2}$  and 600% by 3000  $\text{kg cm}^{-2}$  (44 000 lb. in.<sup>-2</sup>) [*Report of Research Sub-committee on Lubrication, Amer. Soc. Mech. Engineers*, No. 1833 (Dec. 1921)].

## 8. MELTING POINT

General index No.	M. P., °C	General index No.	M. P., °C	General index No.	M. P., °C
4	16	117	20-28	148	32
11	22.4	118	29	149	37.5-42
20	-2 to -6	119	27-43	150	29.8-45.5
23	-4	120	23-30	151	42-50
32	ca. 8	121	30-30.5	152	47-49
52	Below -17	122	30.2-31	153	27.5-32.5
54	Below -18	123	41-42	155	48-54
65	-12 to -28	124	29-33	156	18-39
96	24.9 (pulp)	125	28-31	157	33-40
	19.4-24 (kernel)	126	32-36	158	35-46
97	38-39	130	10-24	159	41-51
98	40-41	131	35-40	160	44-45
100	35 (pulp)	132	38-42	161	28-36
	30.6-32.5 (kernel)	133	27-28.5	164	83-91
101	22-24	135	40-48	165	68-70
102	26.1	136	38-51	166	76
103	23.6	137	37.8		95-97*
105	23-29	138	39-43	167	39-42
106	42	140	26.5-27	168	65-66
107	28-31	141	4-18	169	62-66
109	25-35	142	32	170	62-66
110	32	144	53-56	171	81-83
111	37-42	145	22-28	172	42-49
113	37	146	36-46		
114	15-30	147	26.6-34.5		
116	29.5-35.5				

\* Montan wax.

## UNDER PRESSURE No. 172 (49)

P., atm.	M. P., °C	P., atm.	M. P., °C	P., atm.	M. P., °C
1	46.5	56	49.36	141	50.90
11	48.33	96	50.10	182	51.38
20	48.64				

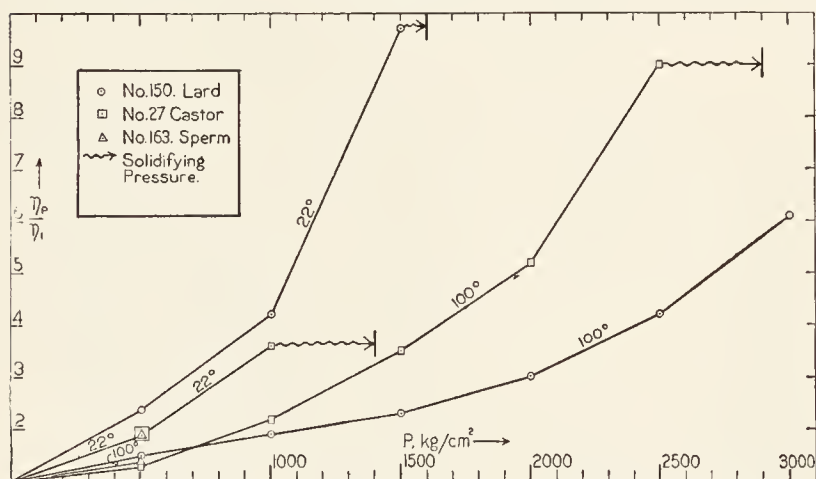


FIG. 1.—Effect of pressure on relative viscosity of oils.

## 9. BOILING POINT OF OILS

No. 27, castor, *ca.* 265°C. No. 67, linseed, *ca.* 287°C. B. P. varies with time owing to decomposition.

## 10. THERMAL EXPANSION

The value of  $d_{15.5}^t$  for any oil for temperatures between 10° and 25° may be approximately calculated from the expression  $d_{15.5}^t = d_{15.5}^0(1 - 0.0007 t) = (\text{approx.})d_{15.5}^{15.5} - 0.0006(t - 15)(210)$ .

VALUES OF  $\frac{d_{15.5}^t - d_{15.5}^{t_2}}{t_2 - t_1} \times 1000$ .  $t_2 = 98^\circ$  or  $99^\circ$  (1)

Values uncorrected for expansion of glass plummet of Westphal balance

General index No.	$t_1^\circ$	Difference for 1°C	General index No.	$t_1^\circ$	Difference for 1°C
117	40	642	159	50	673
119	50	717	161	40	617
120	40	657	164	90	975
144	60	692	169	80	750
147	50	717	172	60	716
150	40	650			

CORRECTION IN DENSITY,  $d_{15.5}^{15.5}$ , FOR 1°C

$$A = -10^3 \frac{dd}{dt} \text{ at } 15^\circ\text{C}$$

General index No.	A	General index No.	A	General index No.	A
3	0.655	41	0.629	84	0.722
8	.629	47	.624	89	.654
20	.620	61	.637	92	.615
27	.653	67	.648	93	.646
29	.658	83	.654	161	.643
31	.625	84	.697	162	.648

## Empirical Equations

$$V_t = V_0(1 + a \times 10^{-6}t + b \times 10^{-6}t^2 + c \times 10^{-9}t^3)$$

General index No.	Name	a	b	c	Range	Lit.
169	Beeswax.....	7386	1.752	-8.27	0-100	(132)
8	Olive oil.....	798	-0.773	8.27	9-106	(214)
8	Olive oil.....	68215	1.14053	5.39		(215)
8	Olive oil.....		$d_4^{20} = 0.91268$ , $d_4^{30} = 0.90590$			(216)

## 11. SPECIFIC HEAT

Mean  $c_p$  between 20° and 30°. 1 joule  $\text{g}^{-1}/^\circ\text{C} = 0.2389 \text{ cal}_{15} \text{ g}^{-1}/^\circ\text{C}$  or  $\text{BTU}_{60} \text{ lb.}^{-1}/^\circ\text{F}$  (130).

General index No.	8	12	20	26	31
$c_p$ , joules $\text{g}^{-1}/^\circ\text{C}$ .....	1.988	2.051	1.963	2.084	1.913
General index No.....	40	47	52, 53	67	
$c_p$ , joules $\text{g}^{-1}/^\circ\text{C}$ .....	1.984	2.000	1.833	1.846	
General index No.....	91	117	150	163	169 (221)
$c_p$ , joules $\text{g}^{-1}/^\circ\text{C}$ .....	1.891	2.139	2.021	1.938	2.0

For thermal conductivity of beeswax *v. p.* 311.

## 12. HEAT OF COMBUSTION

$H_v$  = heat of combustion, at constant volume, in kilojoules per gram. 1  $\text{kJ g}^{-1} = 238.9 \text{ cal}_{15} \text{ g}^{-1} = 430.1 \text{ BTU}_{60} \text{ lb.}^{-1}$

General index No.	Oil	Iodine value	Free acids as oleic	$H_v$ (166)
3	Arachis.....	105.9	0.16	39.39
8	Olive.....	85.1	2.51	39.58
13	Almond.....	98.1	5.13	39.56
20	Rape.....	107.4	0.82	39.71
27	Castor.....	84.1	0.26	37.09
47	Sesame.....	105.3	1.65	39.32
51	Maize.....	120.3	3.32	39.39
51	Maize (crude).....	122.4	1.68	39.42
67	Linseed (fresh).....	182.4	4.30	39.19



General index No.	Oil	Iodine value	Free acids as oleic	$H_v$ (166)
69	Poppy.....	129.6	2.66	39.26
83	Menhaden.....		0.36	39.17
84	Whale.....			39.64
91	Cod liver.....	165.6	0.56	39.49
93	Shark.....			39.22
150	Lard.....	74.3	0.74	39.55
163	Sperm.....	78.7	0.78	41.62

General index No.	Fat	$H_v$	Lit.
150	Lard.....	39.77-40.40	
	Oleomargarine.....	40.18	
161	Butter fat.....	$\left\{ \begin{array}{l} 39.00-39.18 \\ 38.47-38.63 \end{array} \right\}$	(173)
153	Goose fat.....	39.77	(173)
172	Spermaceti.....	41.62	(166)

$H_v \times d_{15}^{15} = 36-37$ . For  $H_v$  of fatty acids *v.* (173).

### 13. FLASH POINTS OF OILS AND FATS

See also (12, 158)

#### 1. Closed Test (42)

General index No.	Oil or fat	Average value		Extreme values, °F
		°F	°C	
8	Olive.....	437.5	225.2	410-465
162	Arctic sperm.....	446.2	230	390-485
163	Southern sperm.....	457.5	236.3	420-485
20	Rape, Black Sea refined....	464.4	240.2	430-490
31	Neat's foot.....	470.3	243.5	410-540
84	White whale.....	476.0	246.4	430-530
20	Rape oil, E. Indian refined.	478.6	248.1	410-510
41	Cottonseed.....	523.0	272.7	500-540

#### 2. Methods Not Stated (8)

General index No.	Oil or fat	Flash point		Fire point	
		°F	°C	°F	°C
67	Linseed.....	378	192	572	300
67	Linseed, boiled.....	419	215	468	242
150	Lard, No. 2.....	419	215	468	242
163	Sperm, No. 1.....	428	220	518	270
31	Neat's foot.....	439	226	523	273
8	Olive.....	451	233	541	283
27	Castor.....	459	237		
51	Maize (corn).....	480	249	635	237
163	Sperm, No. 2.....	486	252	574	302
150	Prime lard.....	530	277	644	340
41	Cottonseed.....	582	305.6	644	340

### 14. ELECTRICAL CONDUCTIVITY

$\kappa = A \times 10^{-5}$  mhos (*cf.* vol. 1, p. 35) (90)

General index No.		$A (= \kappa \times 10^5)$ at 18°C
161	Butter	646-701
	Margarine	822-863
41	Cottonseed oil	863
3	Arachis oil	872
47	Sesame oil	878
8	Olive oil	993

### RELATIVE VALUES ON AN ARBITRARY SCALE (15)

General index No.	8	8	47	69	21	1
°C	Olive I	Olive II	Sesame	Poppy	Ravi-son rape	Peach kernel
0	0.00	0.00	0.2	0.48	7.9	42
20	0.00	0.00	0.9	3.2	19.4	132
40	0.00	0.06	1.7	7.0	45	252
60	0.00	0.14	2.3	17.0	108	501
80	0.00	0.70	8.6	34.9	168	1024
100	0.00		18.0	60.5	236	1748
120	0.01		28.8	115	340	2974
140	0.06		47.0	218	480	4400
160	0.51		107		670	6230
180	1.62	7.62	182.5		1000	8700
200	3.38	10.7	275		1450	11600
220	6.08	15.0	400		2030	14700
240	10.4	21.6	660		2840	18280
260	16.5	33.0	1200		4000	22250
280	23.7	52.5	2270		6000	27750
300	31.70	83.0				

Drying oils heated in contact with air acquire greater conductivity; also oils that have become rancid. If a definite temperature has not been reached (about 260°) the original conductivity is restored on cooling. Of the oils tested, linseed oil showed the greatest conductivity.

General index No.	FATS				WAXES			
	157	150	88	117	172	169	164	144
°C	Chicken fat	Lard	Dolphin oil	Coco-nut oil	Spermaceti	Bees-wax (yellow)	Car-nauba wax	Japan wax
0	1.7				0.0	0.0	14.5	0.0
20	2.2	6.6	5.8	0.48	0.02	0.10	28.0	0.0
40	3.3	8.8	9.4	1.25	1.3	1.0	55.6	0.0
		(liquid)	(liquid)	(liquid)	(liquid)			
60	5.3	18.5	14.8	5.02	2.9	7.1	85.5	0.0
80	7.8	24.0	30.9	7.80		29.0	100	19.0
						(liquid)		(liquid)
100	11.0	28.5	58.0	14.0	4.5	36.0	175	27
120	14.1	38.0	87.5	22.4	8.6	64.0	316	50
140	17.6	61	157.4	33.7	13.6	121	520	90
160	21.5	101	280.0	48.0	19.0	260	1090	155
180	25.4	126	369	102	24.2	600		236
200	30.0	60	470		30.8			343
220	35.1	60.5	625					641
240	40.5	99	880					
260	46.8	158						
280	54.0	230						
300	63.5	339						

### 15. DIELECTRIC CONSTANTS

Mixtures of Castor Oil (No. 27) and Toluene (167, 107, 193); *cf.* (7)

Per cent castor oil	0	10	20	30	40
$\epsilon$ at 12.5°.....	2.655	2.820	3.102	3.264	3.452
$\epsilon$ at 20.0°.....	2.541	2.748	2.920	3.150	3.352
$-\frac{\Delta\epsilon}{\Delta t}$ .....	0.0141	0.0158	0.0174	0.0190	0.0206

Per cent castor oil	50	60	70	80	90	100
$\epsilon$ at 12.5°.....	3.746	3.952	4.152	4.308	4.564	4.798
$\epsilon$ at 20.0°.....	3.536	3.684	3.950	4.182	4.334	4.578
$-\frac{\Delta\epsilon}{\Delta t}$ .....	0.0223	0.0239	0.0255	0.0272	0.0288	0.0304

For castor, olive, and linseed oils see (222).

# 16. REFRACTIVE INDEX AND BUTYROREFRACTOMETER READING

In preparing Table 16B below, butyrorefractometer values have first been converted into values of  $n_D$  by means of the *conversion factors* given in Table 16A. Values of  $n_D$  below 25° and above 40°C have then been converted to 25° and 40°, respectively, by means of the convenient approximate relation,

$$\frac{\Delta n_D}{\Delta t} = -0.00037 \text{ (106).}$$

16A. TABLE FOR CONVERTING BUTYROREFRACTOMETER READINGS INTO REFRACTIVE INDICES

Scale divi- sions	$n_D$	Scale divi- sions	$n_D$	Scale divi- sions	$n_D$	Scale divi- sions	$n_D$
0.0	1.4220	19.5	1.4373	45.2	1.4560	72.7	1.4740
0.5	1.4224	20.0	1.4377	46.0	1.4566	73.5	1.4745
1.0	1.4228	20.4	1.4380	46.6	1.4570	74.3	1.4750
1.2	1.4230	21.1	1.4385	47.3	1.4575	75.1	1.4755
1.5	1.4232	21.7	1.4390	48.0	1.4580	76.0	1.4760
2.0	1.4236	22.5	1.4396	48.8	1.4585	76.8	1.4765
2.5	1.4240	23.0	1.4400	49.5	1.4590	77.7	1.4770
3.0	1.4244	23.5	1.4404	50.2	1.4595	78.6	1.4775
3.5	1.4248	24.3	1.4410	51.0	1.4600	79.4	1.4780
3.7	1.4250	25.0	1.4415	51.7	1.4607	80.3	1.4785
4.0	1.4254	25.6	1.4420	52.5	1.4610	81.2	1.4790
4.5	1.4256	26.3	1.4425	53.3	1.4615	82.0	1.4795
5.0	1.4260	27.0	1.4430	54.0	1.4620	82.9	1.4800
5.5	1.4264	28.3	1.4440	54.8	1.4625	83.8	1.4805
6.0	1.4268	29.0	1.4445	55.6	1.4630	84.6	1.4810
6.2	1.4270	29.7	1.4450	56.3	1.4635	85.5	1.4815
7.0	1.4276	30.0	1.4452	57.1	1.4640	86.4	1.4820
7.5	1.4280	31.0	1.4460	57.9	1.4645	87.3	1.4825
8.0	1.4284	31.8	1.4465	58.6	1.4650	88.2	1.4830
8.7	1.4290	32.5	1.4470	59.4	1.4655	89.1	1.4835
9.0	1.4292	33.0	1.4474	60.2	1.4660	90.0	1.4840
9.5	1.4296	33.9	1.4480	60.9	1.4665	90.9	1.4845
10.0	1.4300	34.6	1.4485	61.7	1.4670	91.8	1.4850
10.5	1.4304	35.3	1.4490	62.5	1.4675	92.7	1.4855
11.0	1.4308	36.0	1.4495	63.2	1.4680	93.6	1.4860
11.3	1.4310	36.7	1.4500	64.0	1.4685	94.0	1.4862
12.0	1.4316	38.1	1.4510	64.8	1.4690	94.5	1.4865
12.5	1.4320	38.7	1.4515	65.6	1.4695	95.4	1.4870
13.8	1.4330	39.5	1.4520	66.4	1.4700	96.0	1.4873
15.0	1.4340	40.0	1.4524	67.2	1.4705	96.3	1.4875
15.5	1.4343	40.9	1.4530	68.0	1.4710	97.2	1.4880
16.4	1.4350	41.5	1.4535	68.7	1.4715	98.1	1.4885
17.0	1.4354	42.3	1.4540	69.5	1.4720	99.1	1.4890
17.8	1.4360	43.0	1.4545	70.3	1.4725	100.0	1.4895
18.5	1.4366	43.7	1.4550	71.1	1.4730		
19.1	1.4370	44.4	1.4555	71.9	1.4735		

For more extensive data *v.* (106). For specific refraction (Lorenz) *v.* (156).

The following empirical relations have been proposed:

$$\frac{n^2 - 1}{n^2 + 2} \times \frac{100}{d_4^t} = 33.07 + 0.00075(I) - 0.01375(S) + 0.002(t - 15)$$

where  $d$  = density,  $S$  = saponification value, and  $I$  = iodine value, all at  $t^\circ\text{C}$ . When hydroxy acids are present, the first constant of the equation is lower (14).

$$n_D^{40} = 1.4643 - 0.000046(S) - 0.0096\left(\frac{A}{S}\right) + 0.0001171(I),$$

where  $A$  = acid value.

An observed refractive index higher than that calculated from this formula indicates oxidation of the oil (149).

In the case of hydrogenated cottonseed, linseed, arachis, sesame and sardine oils, and bassia tallow,

$$n_D^{60} = [1.4468 + 1.03 \times 10^{-4}(I) + 7.3 \times 10^{-3}(I^2)] \pm 0.0005.$$

The refractive indices of hydrogenated castor oil are lower than those of other oils with similar iodine values, owing to reduction of the hydroxyl groups by the catalyst (178).

16B. REFRACTIVE INDICES

Finding No.	General index No.	$n_D^{25}$	$n_D^{40}$
1	117	1.453	1.4477-95
2	127	1.4543	
3	101		1.4490-6
4	132		1.4499
5	118		1.4496-505
6	100		1.4497-506
7	103		1.4503
8	135		1.4511
9	133		1.4512
10	96		1.4502-25
11	162	1.4567-71	1.4511-5
12	120		1.4492-543
13	146		1.4470-579
14	154		1.4499-551
15	161*		1.4528
16	163	1.4573	1.4488-581
17	98		1.4540
18	168-170		1.4538-66
19	99		1.4521-85
20	104		1.4552-656
21	147		1.4537-80
22	97	1.4605	
23	125		1.4559-66
24	150	1.4609-20	1.4542-81
25	142	1.4617	1.4559-66
26	88†	1.4517-717	
27	161‡		1.4534-89
28	152		1.4545-85
29	123	1.4628	1.4566
30	161		1.4555-78
31	116		1.4567
32	89	1.4622-5	1.4568
33	165		1.4569
34	144		1.4560-91
35	149		1.4575
36	157		1.4580
37	11	1.4535-633	1.4581
38	15	1.4635	
39	99		1.4521-85
40	138		1.4588-600
41	105		1.4578-614
42	145		1.4597
43	4		1.4593-613
43.1	131		1.4593-624
44	153		1.4583-626
45	29		1.4607
46	105		1.4605-13
47	31	1.4643-85	
48	139		1.4610
48.5	16.7	1.4664	
49	88	1.4665	
50	107		1.4609-16
51	134		1.4607-20

\* Indian cow.

† Japanese.

‡ Indian buffalo.



## 16B. REFRACTIVE INDICES.—(Continued)

Finding No.	General index No.	$n_D^{25}$	$n_D^{40}$
52	5	1.4667	
53	108		1.4584-649
54	17	1.4662-89	
55	17		1.4618
56	33	1.4671	
57	12	1.4672	
58	13		1.4593-646
59	119		1.4603-39
60	7		1.4593-652
61	2		1.4623
62	112	1.4678	1.4623
63	8	1.4657-67	1.4603-56
64	39		1.4602-57
65	9	1.4682-8	
66	3		1.4620-53
67	26	1.4681-91	1.4636
68	16	1.4679-702	
69	1	1.4682-701	1.4630-49
70	14	1.4636-705	1.4635-49
70.5	35.5		1.4641
71	23	1.4640-6	1.4642
72	76	1.4698	1.4643
73	40	1.4698	
74	141		1.4637-54
75	24		1.4649
76	87		1.4633-66
77	6	1.4705	
78	19	1.4710	1.4650
79	124	1.4700-25*	1.4646-54
80	22		1.4653
81	111		1.4642-64
81.5	16.5		1.4654
82	20		1.4649-59
83	35		1.4656
84	156	1.4658-702	1.4618-96
85	10	1.4711	
86	51	1.4733	1.4656-62
86.5	43.5		1.4660
87	47	1.4704-17†	1.4649-75
88	25	1.4718	
89	28	1.4713-25	1.4659-78
90	68	1.4724	1.4671-8
91	57		1.4675
92	94	1.4730	1.4675
93	63		1.4666-85
94	21	1.4710-74	
95	38	1.4724-39	
96	48	1.4723-56	1.4675-82
97	44	1.4715-36	1.4679
98	79		1.4678-85
99	95	1.4731-43	
100	50	1.4751	
101	73	1.4756	
102	59	1.4769	1.4679-91
103	84	1.4679-724	1.4659-713
104	164		1.4672-701
105	80		1.4685
105.5	56.5		1.4688
106	69	1.4739-42	1.4679-98
107	34	1.4743	
108	62		1.4659-721

\* U. S. A. Standard.

† U. S. A. limits.

Finding No.	General index No.	$n_D^{25}$	$n_D^{40}$
109	92	1.4742-62	1.4685-702
110	27	1.4771	1.4659-730
111	54, 56	1.4760-90	1.4696
112	85		1.4665-729
113	65	1.4770	1.4690-710
114	32		1.4701
115	37		1.4710
116	74		1.4710
117	137		1.4710
118	91	1.4758-83	1.4702-35
119	94.5	1.4701-852	
121	93	1.4825	1.4685-770
122	42	1.4775-91	1.4721-39
123	83	1.4787	1.4731-6
124	126	1.4783	1.4735
125	68.5		1.474
126	58		1.4740-5
127	67	1.4807-15*	1.4739-48
128	67	1.4797-802†	
130	49	1.4777-9	1.4720-74
131	143	1.4770	1.4723-72
132	113		1.4737-60
133	71		1.4753
134	86	1.4763-852	
135	82	1.4818	1.4768-72
137	45.3	1.474	
138	45.5	1.475	
140	42.2	1.4750	
141	167		1.4784-822
142	42.2	1.4778	
143	41.5	1.4780	
144	42.4	1.4780	
145	42.3	1.4786	
146	78		1.4861
147	81	1.4857	
148	60	1.4953	
149	52, 53, 55	1.515-20‡	1.5080-128
150	70	1.5099-186	

\* Russian.

† American.

‡ Am. Soc. Testing Materials limits.

## 16C. OPTICAL DISPERSION

$$\omega = \frac{n_F - n_C}{n_D - 1}$$

Fryer and Weston (67) at 40°

General index No.	$n_D$	$n_F - n_C$	$1/\omega$
1	1.46439	0.00910	51.0
3	1.46431	0.00878	52.9
8	1.46184	0.00862	53.6
13	1.46403	0.00890	52.1
20	1.46770	0.00936	50.0
27	1.47194	0.00897	52.7
41	1.46535	0.00910	51.1
47	1.46650	0.00908	51.3
51	1.46711	0.00938	49.8
52	1.51256	0.01904	26.9
58	1.47404	0.00980	48.4
61	1.46968	0.00935	50.2
62	1.47211	0.00973	48.5
65	1.47054	0.00985	47.8
67	1.47379	0.01032	45.1

## 16C. OPTICAL DISPERSION.—(Continued)

General index No.	$n_D$	$n_F - n_C$	$1/\omega$
69	1.46984	0.00978	48.0
71	1.47527	0.00984	48.3
83	1.47361	0.00979	48.4
84	1.46630	0.00918	50.8
92	1.47018	0.00918	50.8
93	1.46849	0.00955	49.0
117	1.44924	0.00751	59.8
120	1.45034	0.00812	55.4
147	1.45724	0.00853	53.6
150	1.45928	0.00851	53.8
161	1.45427	0.00830	54.7
163	1.45814	0.00864	53.0
172	1.44066*	0.00740	59.5

SZALAGYI (177) AT 45°

3	1.46444	0.00949	48.9
8	1.46040	0.00877	52.5
20	1.46553	0.00933	49.9
27	1.47027	0.00904	52.0
41	1.46394	0.00917	48.7
47	1.46398	0.00917	50.6
58	1.46889	0.00962	48.7
67	1.47224	0.01018	45.1
91	1.46984	0.00988	47.5
117	1.44746	0.00739	60.5
150	1.45716	0.00818	55.9
150	1.45753	0.00882	51.9
161	1.45213	0.00830	54.4
161	1.45296	0.00784	57.6

\* At 56°.

(<sup>93</sup>) describes a method based on the inversion of the spectrum colors shown by tung oil.

## 17. OPTICAL ROTATION OF OILS

Values expressed in reading on Laurent's saccharimeter (200 mm at 20°) unless otherwise stated (148)

General index No.	Oil or fat	Optical rotation
69	Poppy oil.....	0.0
3	Arachis oil.....	-0.1 to -0.4
14	Apricot kernel oil.....	-0.2
65	Walnut oil.....	-0.3
13	Almond oil.....	-0.7
20	Rape oil.....	-1.6 to -2.1
82	Stillingia oil.....	-18.6
8	Olive oil.....	+0.2 to +0.6
47	Sesame oil.....	+0.8 to +2.4
27	Castor oil.....	+7.6 to +9
37	Croton oil.....	+14.5 to +16.4
42	Hydnocarpus oil $\alpha_D^{20}$ .....	+49.50 to +51.5
49	Chaulmoogra oil $\alpha_D^{20}$ .....	+50.8 to +58.2

## PROPERTY-SUBSTANCE TABLES

The bold-faced numbers are intervals on the scale of property values. The other numbers are General Index Numbers in the order of the value of the property.

## 18. DENSITY

*Oils.*—15/15: **0.861**: 163, 162, 6, 88, 94.5. **0.91**: 88, and all others except 60. **0.95**: 49, 27, 60, 42.2. **0.97**.

*Fats.*—100/15.5: **0.862**: 148, 138, 141, 149, 125, 116, 119, 147, 131, 108, 115, 109, 111, 99, 130, 146, 117. **0.86**: 141, 146, 117, and all others except 155. **0.90**: 155. **0.91**.

*Waxes.*—100/15.5: **0.805**: 172, 171, 169, 167, 164. **0.85**.

## 19. MELTING POINT

*Fats.*—4°: 141. 10°: 141, 130, 114, 156, 96. 20°: 130, 114, 156, 117, 145, 101, 103, 105, 120, 96. 25°: 114, 156, 117, 145, 105, 120, 109, 102, 140, 147, 119, 133, 153, 125, 107, 161, 100, 118, 116, 124, 150. 30°: 156, 109, 147, 119, 153, 125, 107, 161, 116, 124, 150, 121, 148, 142, 126, 110, 157. 35°: 156, 119, 161, 116, 150, 126, 157, 158, 131, 146, 113, 111, 149, 137, 97, 132, 136, 167, 138. 40°: 119, 150, 158, 146, 111, 149, 132, 136, 167, 138, 98, 135, 123, 159, 106, 172, 151, 160. 45°: 150, 158, 146, 136, 135, 159, 172, 151, 152, 155, 144. 50°: 136, 159, 155, 144. 60°: 169, 170, 168, 165. 70°: 166. 80°: 171, 164. 90°: 166, 164.

## 20. CONGELATION TEMPERATURE

*Oils.*—-30°: 66, 59, 51, 80, 65, 79, 58, 73, 67, 77, 13. -20°: 51, 65, 58, 77, 13, 81, 54, 66, 59, 51, 80, 65, 79, 58, 73, 67, 77, 13, 81, 54, 52, 53, 15, 74, 14, 1, 45, 34, 69, 5, 27, 37, 28, 75, 40, 25, 68, 62, 24, 88, 38. -15°: 51, 65, 77, 13, 14, 45, 27, 37, 28, 48, 23, 43, 41, 61, 64, 17. -10°: 37, 39, 12, 16, 10, 46, 20, 21, 3, 36, 8. -5°: 20, 3, 8, 47, 83, 99, 91, 84, 29, 31, 30, 92, 82. 0°: 41, 99, 29, 31, 53, 30, 7, 95, 33, 26, 6. 5°: 41, 31, 30, 4, 45.3. 10°: 41, 30, 4, 11, 42.4, 42.5. 20°: 30, 42.3, 42.2, 42.1, 41.5. 75°.

## 21. ACETYL VALUE

0: 91, 161, 117, 172, 150, 147, 3. 3: 3, 5, 163, 13. 5: 163, 13, 51, 116, 26, 120, 58, 31, 159, 54. 10: 51, 26, 54, 8, 65, 125, 84, 44, 69, 160, 36, 20, 41, 28. 15: 26, 84, 37.5, 44, 41, 169, 92, 119, 59, 153, 28, 144, 37. 20: 26, 84, 44, 41, 144, 68, 141, 63, 82, 28. 30: 141, 37, 28, 113. 40: 28, 2. 50: 164. 55: 149: 27. 150.

## 22. IODINE VALUE

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## 23. SAPONIFICATION VALUE

50: 165, 166, 164, 167, 168, 169, 170. 100: 167, 168, 170, 163, 162, 172. 150: 136, 93, 84, 20, 94, 85, 72, 91, 24, 28, 19, 25, 6, 23, 27, 21, 90, 146, 143, 111. 180: 84, 85, 91, 28, 19, 27, 21, 90, 143, 111, 146, 43, 108, 76, 16.7, 130, 9, 141, 50, 13, 66, 134, 7, 8, 137, 142, 51, 3, 88, 60, 123, 98, 44, 92, 34, 36, 148, 68, 106, 104, 38, 47, 62, 71, 4, 67, 86, 59, 96, 61, 87, 107, 149, 48, 83, 39, 54, 49. 190: 84, 85, 28, 146, 130, 13, 8, 42.3, 68.5, 137, 142, 51, 139.5, 3, 123, 98, 44, 42.5, 92, 68, 104, 38, 47, 62, 71, 4, 67, 86, 59, 61, 87, 107, 149, 37.5, 48, 83, 39, 54, 49, 35, 80, 32, 99, 64, 17, 95, 81, 58, 160, 65, 63, 12, 78, 75, 18, 1, 16, 79, 153, 40, 5, 14, 73, 74, 125, 139, 110, 10, 26, 33, 57, 45, 69, 147, 15, 70, 29, 159, 30, 31, 105, 114, 157, 37, 113, 41, 52, 53, 55, 2. 195: 84, 13, 8, 137, 142, 92, 86, 59, 49, 160, 65, 63, 40, 5, 14, 10, 26, 70, 29, 159, 30, 31, 105, 114, 157, 37, 41, 52, 53, 55, 2, 109, 152, 155, 156, 150, 112, 151, 115, 121, 126, 46, 116, 158, 131, 119, 56, 89, 135. 42. 144, 82, 42, 45.3, 41.5, 42.2.

<sup>1</sup> See Table 3.



42.4. **210:** 37, 131, 135, 144, 161, 11, 145, 138, 100, 122, 154, 96, 100. **240:** 96, 100, 132, 133, 190, 97, 102. **250:** 89, 96, 133, 190, 118, 117, 101, 128, 103. **260:** 117, 140, 127, 89. **280:** 129, 85 290.

#### 24. HEHNER VALUE

**65:** 88, 89. **82:** 97, 117, 127, 128, 129, 140, 161, 93, 17. **90:** 117, 93, 17, 120, 16.7, 144, 145. **92:** 3.5, 4, 16.6, 18, 28, 48, 51, 65, 66, 74, 77, 79, 84, 88, 95, 106, 108, 109, 111, 113, 119, 131, 132, 135, 138, 141, 142, 147, 149, 150, 153, 157, 160, 81, 87. **95:** 93, 119, 141, and all others for which data are available. **96:** 0.5, 12, 93, 119, 141, 86, 151. **97:** 29, 81, 87, 156, 158.

#### 25. REICHERT-MEISSL VALUES

General index No.	Reichert-Meissl value	General index No.	Reichert-Meissl value
57	0.0	65	0.92
59	0 -1.2	31	0.9 -1.2
20	0 -0.79	119	0.9 -1.9
17	0.1	41	0.95
114	0.1	82	0.93-0.99
44	0.1 -1.3	67	0.95
123	0.11-1.54	5	0.99
91, 92	0.2	143	1
14	0.2	106	1 -2
124	0.22	131	1 -4
132	0.2 -0.4	42	1.02
43	0.2 -0.4	53	1.1
149	0.2 -0.4	125	1.1
153	0.2 -0.8	47	1.1 -1.2
146	0.2 -0.9	108	1.1 -2.5
160	0.2 -1.7	136	1.1 -4.2
26	0.28-0.48	54	1.2
142	0.3	83	1.2
147	0.3 -1.0	111	1.25-1.4
110	0.33	127	1.39
37.5	0.33	27	1.4
19	0.33-0.89	66	1.5
55	0.35	126	1.6
113	0.38	157	1.8
52	0.39	74	2.0
3	0.4	129	2.0
90	0.4 -0.7	50	2 -3
104	0.4 -1.31	4	2.5 -3.3
69	0.4 -3.0	128	2.53
105	0.44-0.88	133	3.0
28	0.46	95	3.4
7, 13	0.5	100	3.8
62, 138	0.5	51	4.2 -9.9
112	0.5	140	4.5
48	0.5 -2.8	38	4.45
86	0.5 -1	120	5 -6.8
159	0.5 -1	88	5.6
36	0.55	96	5.7 -7.2
2, 69	0.6	102	5.8
141	0.6	103	6.3
107	0.6 -0.5	117	6.6 -7.5
8	0.6 -1.8	101	8
116	0.65	134	8.27
155	0.68	145	9
158	0.7 -2.8	84	14
23	0.75	161	17.0-34.5
22	0.75	154	20.8-27.7
81	0.75	89 (Body)	64.9
130	0.8 -0.9	88 (Jaw)	65.9
11	0.88	89 (Jaw)	132

#### 26. UNSAPONIFIABLE MATTER

General index No.	%	General index No.	%
31	0.12-0.65	84	1 -4
115	0.19	139	1.1
134	0.25	144	1.1 -1.6
92	0.3 -1.0	57	1.14
103	0.36	51	1.25-1.60
52	0.41	48	1.27-1.54
8	0.4 -1.0	74	1.3
67	0.4 -1 2	68.5	1.3
69	0.43	32	1.30-2.65
5	0.5	104	1.36
54	0.5 -0 9	82	1.45
107	0.5	139.5	1.6
3	0 5 -0.9	88	2
87	0.5 -3.0	50	2.4 -2.6
125	0 5	95	2.61
62	0 51	10	3
155	0.52	25	3.3
91	0.54-2.68	108	3.86
53	0.59	93	2.8 -15.2
29	0.6	111	5 -9
83	0.6 -1.45	133	7.0
90	0.7 -7.0	94	8.4
13	0.75	89	16 -17
100	0.75	137	20.4
86	0.98	162	36 -41
55	0.99	167	39 -44
85	1 -2	166	47
58	1.08	172	51.5
37.5	1.1	164	54 -55
41	1.1	94.5	1 -90

#### 27. MELTING AND SOLIDIFICATION POINTS OF FATTY ACIDS

General index No.	Melting point, fatty acids, °C	Solidification point, fatty acids, "titer" test, °C	General index No.	Melting point, fatty acids, °C	Solidification point, fatty acids, "titer" test, °C
71	-5		51	17 -22	19
64	0		45.3	18	
75	0		20	18.5-20	11.7-13.6
77	0		18	19	10
14	2.3- 4.5		76	19	
162	10.3-10.8	8.3- 8.6	15	19 -21	13 -15
128		9 -10	23	20	13 -15
59	11 -17	7 -12	21		13.5-16.5
163	13.4		63		15 -20
13	13 -14	9.5-11.8	69	20.5	17 -19
34	13 -14		56		17.6
16	13.4-18		67	20 -24	16 -21
84	14 -27	10 -24	96	20.5-21	
82	14.5		60	21.5	
127		13		(begins)	
65	15 -20	14.3		65.0	
25	16 -17	13.4-13.7		(complete)	
43	16 -18		37		17 -19
78	16 -19	10 -16	45	21.7	22 -26
79		10 -15	93	21 -22	
58	17 -21	15.6-16.6	91	21.8-38	17.5 21 3
12	17 -20		5	22 -25	19 -20

# 27. MELTING AND SOLIDIFICATION POINTS OF FATTY ACIDS.—(Continued)

General index No.	Melting point, fatty acids, °C	Solidification point, fatty acids, "titer" test, °C	General index No.	Melting point, fatty acids, °C	Solidification point, fatty acids, "titer" test, °C
92	22 -23		39	38	
62	22 -24	18 -19.8	4	38.8	
66	22.2		157	38 -40	32 -34
57	22.8		161	38 -41	33 -39
46	23		50	39 -40	
28	23 -25		30		35 -37
40	23 -24		158	39 -50	35 -41
36		19.7-21.0			45.2-47.2
68	23 -26	20 -24	146	39 -57	50.9-52.5
103	23.6		105	39 -45	38 -40
26	24 -30		42.4	40	
133	24.2		106		38 -41
117	24 -27	21.2-25.2	114	40 -42	37 -40
120	25 -28.5	20 -25.5	42.2	41	
61	25.4	22.6	167	41.8	
94.5	25 -35		109	42 -46	38 -40
47	25 -35	23 -32	130	42 -49	
8	26 -30	16.9-26.4	151	42.5-44	37.9-46.2
48	26.2-27.5		138	42.5-46	
100	27		42.1	43	
140	27 -28		42.5	43	
101	27 -28		143	44 -45	36 -42
124	27 -45	39.9-51	42	46	
32	27.5		137		37.2
33	28 -30	31.1-32.2	160		42.5-44
31	29 -41	16 -26.5	159		40 -50
81	30 -40		42.3	47	
27	30		135	47 -48	
85	30 -32		116	48.3-50	46 -47
38		26 -28	147	48 -53	47.2-49.2
113		28 -29	108	49 -52.8	47
86	30 -34.8	28.2	119	50	42.5-45.5
3		30.5-39	141	50 -57	
52	30 -49.4	36 -39	155	50 -64	46 -50
90	31		131	51 -55	48 -52
97	31		148		48.1
156	31.3-53.4		111	52 -53	
112	33 -34		145	52 -55	49.7-50.7
29	33 -38.4		144	53 -56.5	
152	33.5-49	40 -48.5	41.5	55	
41	34.5		125	56	
132	35		107	56	
87	35 -36	27.5-28.2	149	56 -57	
99	35 -38		142	57 -60	
153	36.6-40	31 -34	104	58.4	
95	36.5	27 -28	98	59	61.4-61.5
150	37 -46.6	36 -42.4	123	60 -61	
6	37.6				

## HYDROGENATED OILS

Hydrogenation reduces the iodine value, and refractive index, (56) but has little influence upon the acid value, saponification value and unsaponifiable matter.

In oils, such as castor oil, containing hydroxyl groups, the hydroxyl value is lowered (143). The amount of insoluble bromides is reduced. The stearic acid formed on hydrogenation is identical with normal stearic acid (120).

A method of differentiating hydrogenated and natural oils has been based on the ratio between the amounts of stearic acid and palmitic acid (135). Hydrogenated oil may be recognized by a determination of the iso-oleic acid formed in the process (208).

## PARTLY HYDROGENATED OILS (218)

General index No.	Oil	M. P., °C	Con- gelation point, °C	Butyrore- fractometer reading (40°)	Acid value	Saponi- fication value	Iodine value
117	Coconut.....	44.5	27.7	35.9	0.4	254.1	1.0
47	Sesame (techn.)..	62.1	45.3	38.4	4.7	188.9	25.4
84	Whale.....	45.1	33.9	49.1	1.2	192.3	45.2
3	Arachis.....	51.2	36.5	50.1	1.0	188.7	47.4
47	Sesame.....	47.8	33.4	51.5	0.5	190.6	54.8
41	Cottonseed.....	33.5	25.4	53.8	0.6	195.7	69.7

## WHALE OIL (GEN. IND. NO. 84) AT DIFFERENT STAGES OF HYDROGENATION (219)

	M. P., °C	Con- gelation point, °C	Acid value	Saponi- fication value	Iodine value	Molecular equivalence of fatty acids
Original oil.....	Fluid	Fluid	9.50	192.2	144.8	287.7
Artificial tallow.....	47.5	38.1	9.88	183.7	56.9	296.4
Artificial stearine.....	54.3	47.3	7.80	187.7	11.7	297.0
Hydrogenated whale oil..	41.9	31.9	5.30	190.9	57.8	282.9

## COMPLETELY HYDROGENATED OILS (220)

General index No.	Hydrogenated oil or fat	M. P., °C	Iodine value	Saponi- fication value	Fatty acid, M. P., °C
159	Tallow.....	62	0.1	197.7	64
150	Lard.....	64	1.0	196.8	62
147	Cacao butter.....	63.5-64	0.0	193.9	65.5
3	Arachis.....	64-64.5	0.0	191.6	67
91	Cod liver.....	65	1.2	186.2	59
67	Linseed.....	68	0.2	189.6	70.5
47	Sesame.....	68.5	0.7	190.6	69.5
8	Olive.....	70	0.2	190.9	71
69	Poppy.....	70.5	0.3	191.3	71
13	Almond.....	72	0.0	191.8	71

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## ADHESIVES AND GELATINS

JEROME ALEXANDER

## INTRODUCTION

Most practical adhesives are mixtures of several ingredients, with or without some kind of salt, and may be classified as:

(A) Animal adhesives: e.g., glues, gelatins, casein, albumin;

(B) Vegetable adhesives: e.g., flours, starches, dextrans, gums, gum resins, oils, and proteins;

(C) Mineral adhesives: e.g., silicate of soda, cements, limes, plasters, clays, pitches, tars, artificial resins, solders, and such mixtures as iron + sulfur and litharge + glycerin.

In using an adhesive to join two surfaces, the surfaces concerned are the ultimate exterior ones and the adhesive must either take hold of these exterior surfaces or must remove them and take hold on the surface below. Thus, if the articles to be joined are not cleaned, the exterior surface is frequently a layer of grease.

Setting and drying are promoted by any agency which increases the concentration of the adhesive; for example, by removing the solvent. Joint strength is influenced by quantity of adhesive used, by speed of set and drying, and by the application of pressure.

## Animal Glues

Use.—(1) Keep dry and from excessive heat; (2) use definite weights of glue and water; (3) soak glue in cold water until softened; (4) melt on water bath and keep temperature as low as work permits (usually below 65°C); melt small batches successively to avoid prolonged heating which injures strength; (5) supply evaporation losses; (6) use clean vessels, and, if necessary, a preservative.

## SELECTION

**Wood Joints.**—Hide-stock glues, grades 70–130.<sup>1</sup> Joining pressure before setting increases joint strength rapidly up to 200, and then more slowly up to 1000 lb./in.<sup>2</sup>. Surfaces must be well joined, dry, and preferably warm. Good joints are stronger than the wood, and may show shearing strength of 2000 to 3000 lb./in.<sup>2</sup>

**Veneers.**—Bone and hide stock mixtures between 50 and 70. Avoid foam.

**Paper Boxes.**—For hand setting-up, 70 to 90 test; for machine, 100 to 160 test. For covering or stripping, 30 to 60 test.

**Book Binding.**—For rounding and backing, grades above 90 are best (usually mixed with some glycerin). For hand pasting, grades about 50. For ease-making machines, grades 60 to 100.

**Leather Belting, Printer's Rollers, Plaster Molds.**—Hide glues above 120; usually with addition of glycerin, etc.

## Gelatins

**Photographic Gelatin (1).**—Jelly strength, 130 or above. pH, 5–6 (limit 4–7). Ash <3%. Fe and Cu <50–60, Pb <50, parts per million. Al<sub>2</sub>O<sub>3</sub> <0.2%, SO<sub>2</sub> <0.1%, of dry gelatin. Mucin, grease, and ammonia > traces. Traces of thioearbimides are essential<sup>(55)</sup>.

**Food Gelatin.**—U. S. Dept. of Agriculture, Bureau of Chemistry, tolerance limits (parts per million): As<sub>2</sub>O<sub>3</sub>, 1.4; Zn, 100; Cu, 30; Pb, 20; SO<sub>2</sub> must be declared on label.

## 1. ADHESIVES

COMPARISON OF AMERICAN GRADES OF GLUE AND GELATIN  
(1, 5, 22)

Cooper	Alexander			Bogue	National Assn. Glue Mfrs. (U. S. A.)		
Grade	Grade	S*	$\eta$ †	Grade	Grade	S‡	$\eta$ §
	10		15.5 ± 0.25		1	10	20
	20		16 ± 0.25	1	2	27	24
2	30		16.5 ± 0.25	2	3	47	28
1 $\frac{7}{8}$	40	1701	17 ± 0.25	3	4	70	32
1 $\frac{3}{4}$	50	2324	18 ± 0.5	4	5	95	37
1 $\frac{5}{8}$	60	2948	19 ± 0.5	5	6	122	42
1 $\frac{1}{2}$	70	3572	20 ± 0.5	6	7	150	47
1 $\frac{3}{8}$	80	4196	21 ± 0.5	7	8	178	53
1 $\frac{1}{4}$	90	4820	22 ± 0.75	8	9	207	60
1 X	100	5443	23 ± 0.75	9	10	237	67
1	110	6067	24 ± 0.75	10	11	267	75
1 Extra	120	6691	25 ± 1	11	12	299	83
A Extra	130	7314	26 ± 3	12	13	331	92
	140		28 ± 5		14	363	102
	150		34 ± 8		15	395	113
	160		40 ± 12		16	428	125
					17	461	138
					18	495	152
					19	530	167
					20	565	183
					21	600	200

\* Jelly "strength" in grams, Alexander tester.

† Viscosity in seconds (water = 15).

‡ Lower limit of jelly "strength" in grams, Bloom gelometer.

§ Viscosity in millipoises, lower limit.

## SPECIFIC GRAVITY OF GLUE SOLUTIONS (40)

Wt. % glue	$d_{75}^{75}$	°Bé, 54.4°C	°Bé, 32°C	°Bé, 15.6°C
7	1.001			
8	1.003			
9	1.006			
10	1.009	2.2	3.1	4.0

<sup>1</sup> The "grades" here referred to are the Alexander grades listed in Table 1.

## SPECIFIC GRAVITY OF GLUE SOLUTIONS (40).—(Continued)

Wt. % glue	$d_{75}^{75}$	°Bé, 54.4°C	°Bé, 32°C	°Bé, 15.6°C
15	1.023	4.2	5.1	6.0
20	1.037	6.1	7.0	7.9
25	1.051	8.0	9.0	9.8
30	1.065	9.8	10.7	11.6
35	1.079	11.5	12.4	13.3
40	1.093	13.2	14.1	15.0
45	1.107	14.9	15.7	16.5
50	1.121	16.5	17.4	18.3

## NITROGEN CONTENT OF GLUES, Wt. % (10)

H = hide glue; B = bone glue; F = fish glue; P = protein; I = isinglass

Form	H*	B*	F	P	I
Ammonia.....	2.9	4.6	5.2	1.3–3.6	4.0
Melanin.....	0.6	0.9	1.1	0.7	0.7
Cystine.....	0	0	tr	tr	0
Arginine.....	13.9	13.2	13.8	11–12.6	14.2
Histidine.....	2.2	1.8	2.0	0.8–2.2	2.3
Lysine.....	8.0	8.3	8.6	8.3–8.6	6.1
Amino†.....	56.8	56.3	60.2	58–60	58.7
Non-amino†.....	15.6	15.3	9.7	15.5	13.6

\* Av. of 6 samples.

† Soluble.

## Joint Strength

The strength of joints made with an adhesive depends upon the kind of material joined and the condition of its surface, upon the thickness of the adhesive film, and upon such conditions as temperature, humidity, time of drying, and pressure used in forming the joint.

## TENSILE STRENGTH (DEF. 4): OAK TO OAK (32)

Unit: kg/cm<sup>2</sup>

Effect of air humidity and temperature

At $t^{\circ}\text{C}$		15°	20°	25°	25°	
Air humidity		50 %	75 %	90 %	95 %	
Liquid glues	A	* †	49.6	45.8	35.4	26.4
	B		45.7	44.1	39.1	29.0
	C		31.7	31.3	31.1	30.3
	D		42.7	41.2	39.4	37.7

\* Very hygroscopic.

† Slightly hygroscopic.

## TENSILE (TS) AND SHEARING (SS) STRENGTH OF METAL TO METAL JOINTS (21)

A = High grade commercial gelatin. B = Silicate of soda. C = Commercial nitrocellulose cement "A." D = Molten shellac (pure). E = American commercial cement (hard). F = American commercial cement (medium). G = A wax. H = Fish glue. I = Liquid commercial glue "C." J = Rubber solution. K = Marine glue. L = Commercial glue "B." M = Gum arabic. T = Drying or setting time in days. Stl. = Mild steel. Fe = cast iron. Bra. = Brass. Unit: kg/cm<sup>2</sup>.

Adhesive	Days	Metal	Ni	Stl.	Fe	Cu	Bra.	Al	Sn	Pb
A	17	TS	63	70	77	84	49	(21)	56	56
	20	SS		70	49	56	77		35	
B	20	TS	35	49†	49	56†	70	49	35	21
C*	14–21	TS	112	112	98	140	105	119	70	35
	21	SS		49	56	35	35	56	42	28



TENSILE (TS) AND SHEARING (SS) STRENGTH OF METAL TO METAL JOINTS (21).—(Continued)

Adhesive	Days	Metal	Ni	Stl.	Fe	Cu	Bra.	Al	Sn	Pb
D	1-5	TS	246	225	211	232	176	197	77	42
	1-3	SS		239	211	232	232	155		
E	1-2	TS	295	337	309	281	204	162	105	35
	1-3	SS		295	288	288	267	218	77	42
F	1	TS				309		169		
	1	SS		260	225	239	246	147		
G	1-2	TS	84	70	98	70	77	70	56	35
	1	SS	35			35	42	42	42	35
H	16	TS	84	56	84	98	49	70		
	16	SS	35	98	84	77	98	(14)		
I‡	18	TS				21		28	28	
	18	SS		35	28	35	21	21		
J	16	TS			21					
K	4-5	TS	77	120	63		105	98	56	
	4-5	SS	42	84	56	42		63	63	
L	77	TS	88	133	112	112	140	70	77	
	77	SS	88	112	106	105	84	91		
M	77	TS	84	63	77	112	112	49	56	
	77	SS	(98)	88	70	(112)	56	105	56	

\* TS = 28 with amalgamated Cu and 77 with platinized Cu.

† When rough = 21, oxidized = 35.

‡ Amalgamated Cu.

§ TS = 28 with platinized Cu.

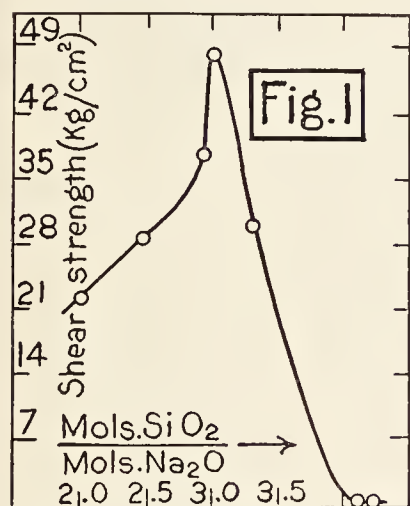


FIG. 1.—Shearing strength of water-glass joints between walnut surfaces (21).

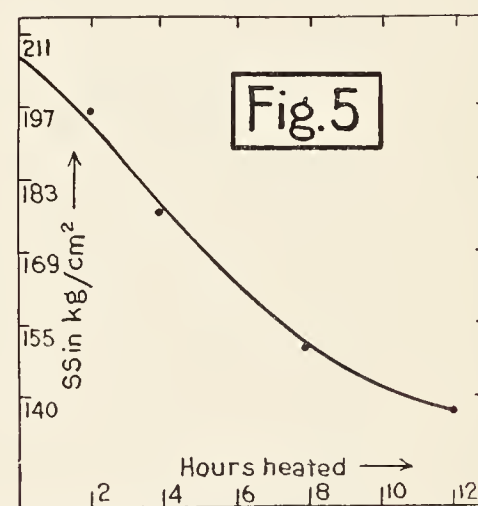
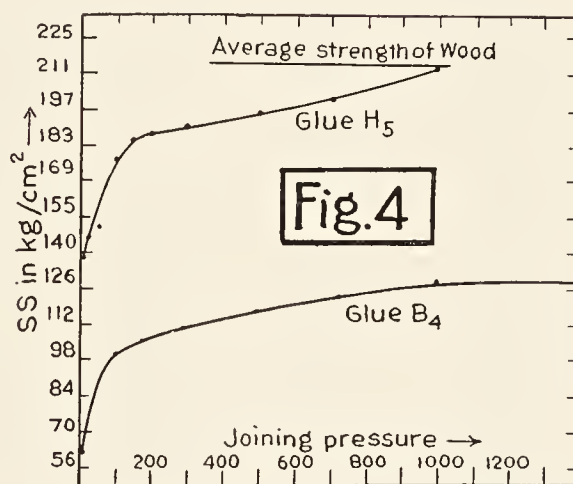
FIG. 4.—Effect of joining pressure (11). Shearing strength of wood to wood joints with a hide glue H<sub>5</sub> and a bone glue B<sub>4</sub>.

FIG. 5.—Effect of heat (11). Shearing strength of wood-to-wood joints made under constant joining pressure of 14 kg/cm² using a glue heated to 80°C.

SHEARING STRENGTH, WALNUT TO WALNUT (21)  
Unit: kg/cm²

Adhesive	Days dried	kg/cm²
Fish glue.....	7	98
Liquid commercial glue "C".....	7	84
High grade gelatin.....	6	84*
Fish glue + bone gelatin.....	7	49
Casein + borax cement.....	6	42
Gum arabic.....	6	28
Commercial glue "B".....	12	28
Casein and silicate cement.....	8	21
Commercial nitrocellulose cement "A".....	30	21
Starch.....	9	21†

\* Reduced to about 30 if the joint be heated to 100° for 4 days while clamped.

† Film not complete. Three coatings raise value to 112; values have been measured as high as 600. Additional data are given in Figs. 1-5.

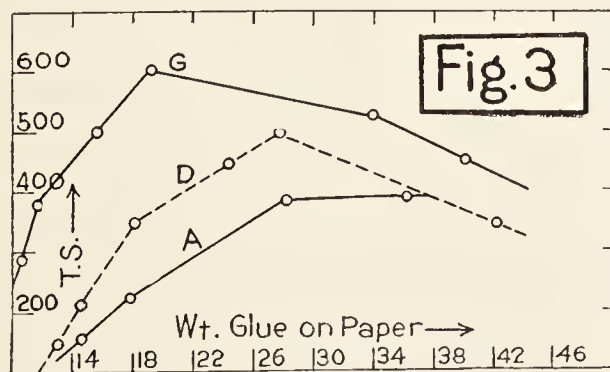


FIG. 3.—Effect of film thickness (2). TS = tearing strength, in kg/cm², of glue.

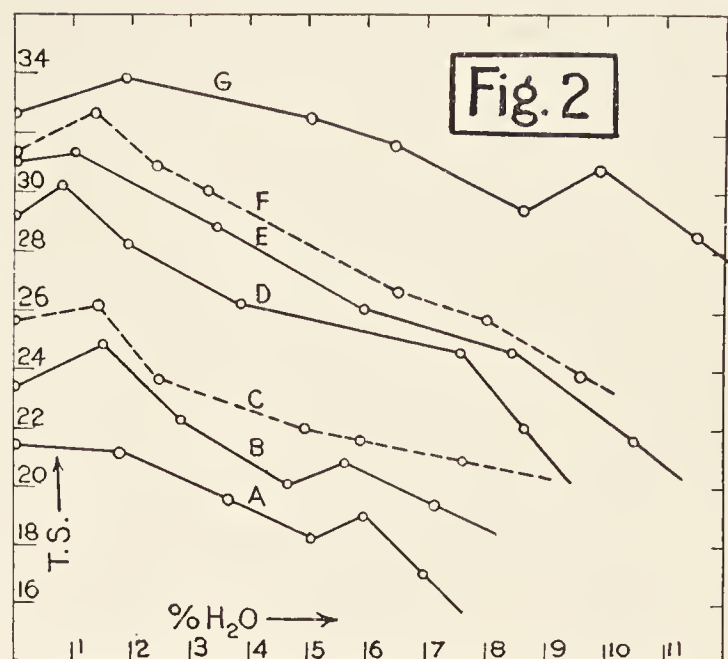


FIG. 2.—Effect of moisture content on joint strength (2). A, B = bone glues. C, D, E, F = hide glues. G = gelatin.

## TENSILE STRENGTH OF SOME COMMON ADHESIVES

Unit: kg/cm<sup>2</sup>

Glue (calculated).....	700-2000
Collagen.....	1300
Gelatin.....	960
Viscose.....	2100

## Jelly Strength

The jelly strength of a glue is usually measured by the force required to cause a definite compression of the jelly. The addition of formaldehyde to glues decreases the jelly strength in direct proportion to the amount of HCHO added, until the glue becomes insoluble. Figure 6 shows the number of cm<sup>3</sup> of 10% HCHO required to produce insolubility in various glues, the numbers on the curve giving the grams of glue to 180 g total weight of solution (7).

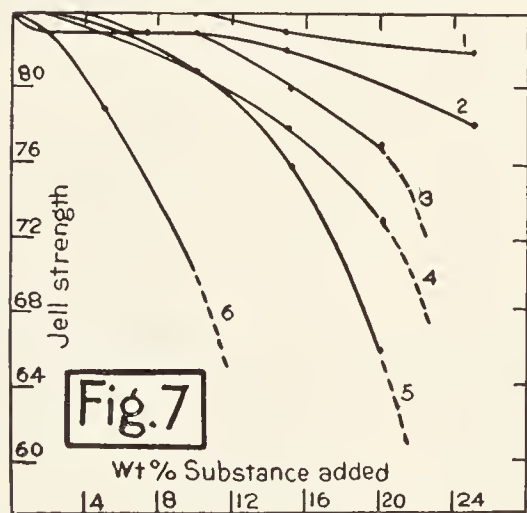
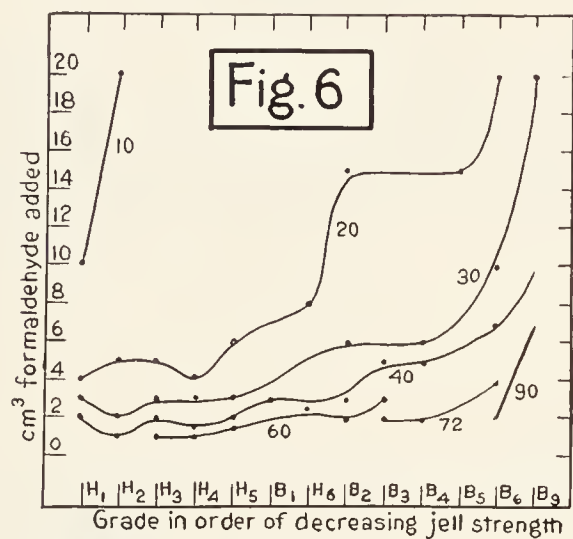


Figure 7 shows the effect of added substances upon the jelly strength. 1 H<sub>2</sub>SO<sub>4</sub>; 2 NaOH; 3 MgCl<sub>2</sub>; 4 Acetic acid; 5 Chloral hydrate; 6 KI. 1 and 2 in cm<sup>3</sup> of 0.5N soln. added instead of wt. % (7).

The relation between the nitrogenous constituents and the jelly strengths of hide (H) and bone (B) glues is shown in Figs. 8 and 9 (9).

Viscosity;  $\eta$ 

The viscosity of 20% solutions of hide and bone glues at 15.5°C (60°F) is constant for at least 90 minutes after preparation. Vigorous agitation lowers  $\eta$  slightly (2% after 2 minutes beating) (7).

The increase in  $\eta$  produced in dilute solutions of glues by formaldehyde is slight, but rises rapidly with increasing glue content. Agitation increases  $\eta$  of HCHO treated glues slightly and after

drying such glues exhibit increased  $\eta$  on re-solution or become insoluble with increasing HCHO content (7).

The amount of protein precipitated by 24-30% MgSO<sub>4</sub> solution from liquid glue varies directly as  $\eta$  for glue solutions having the same jelly strength (9).

The amount of material absorbable from glue solutions decreases as  $\eta$  decreases (34).

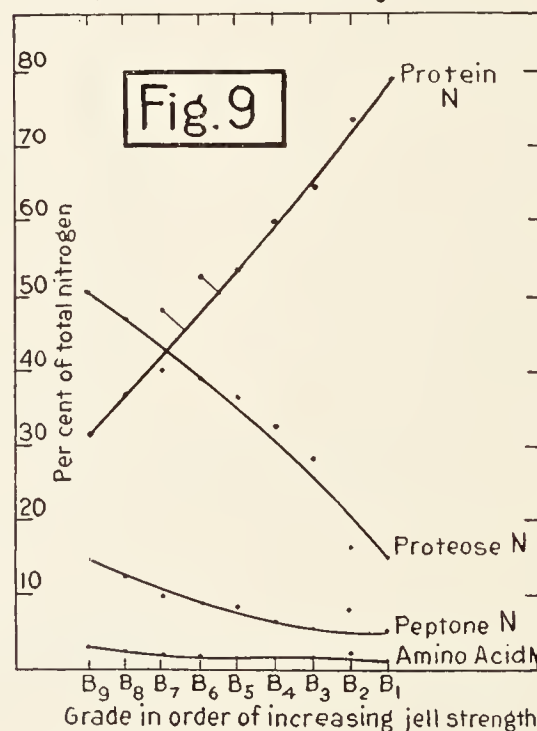
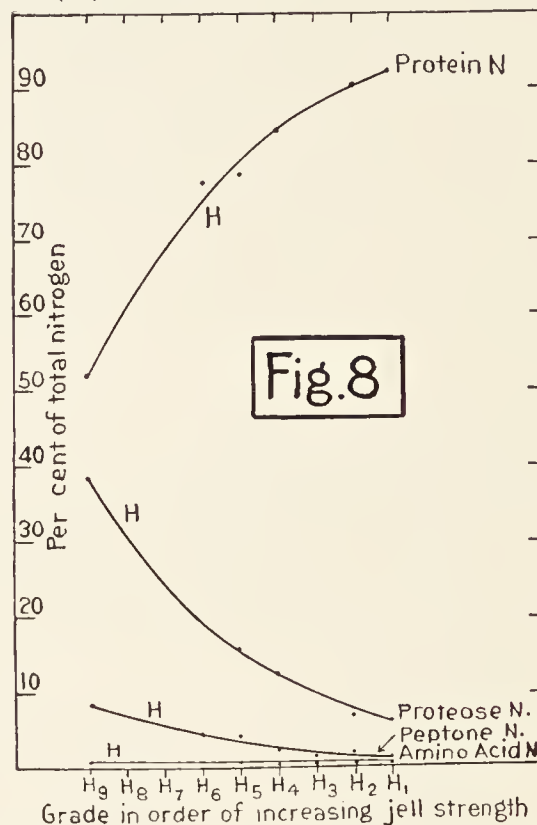


Figure 10 shows the effect of time on  $\eta$  (in seconds, H<sub>2</sub>O = 42) of HCHO treated glues and Fig. 11 the effect of temperature. (Numbers on curve = cm<sup>3</sup>; 10% HCHO added.) (7).

Figure 12 shows the effect of alums on  $\eta$  of glue solutions; Fig. 13 the effect of time, and Fig. 14 the effect of temperature on the  $\eta$  of alum-treated glues (7).

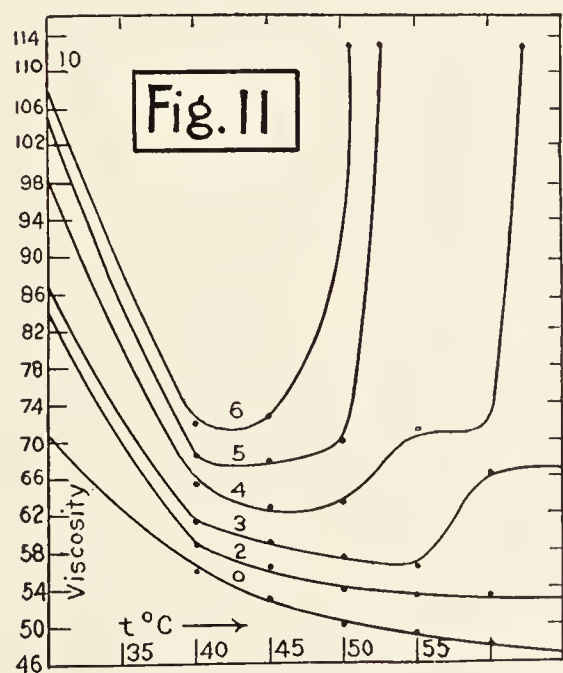
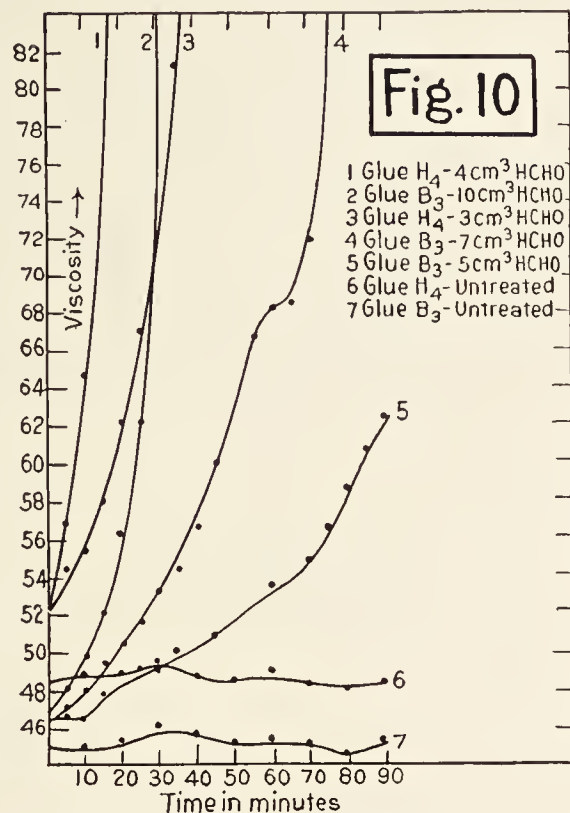
Figure 15 shows the variation of  $\eta$  (in seconds, H<sub>2</sub>O = 42) of glue solutions with temperature, the melting point of the glue solution being taken as temperature at which the slope of the curve approaches infinity (8).



Figure 16 shows the effect of temperature on the  $\eta$  of hide glues, and Fig. 17 on the  $\eta$  of bone glues ( $\eta$  in MacMichael degrees) (8).

Figure 18 shows the relation of  $\eta$  to jelly strength of hide glues (11).

The flow of starch pastes, under pressure, through a capillary tube is shown in Fig. 19 and of dextrin pastes in Fig. 20. The numbers on the curves give the wt. % of dry solids in the pastes (16).



The  $\eta$  of 10% hide and glue solutions, measured at 35°C, is decreased considerably by heating under pressure up to 5 atm. for 1 to 5 hr. (23).

Addition of anhydrous chrome alum in small percentages has little or no effect on the  $\eta$  of glue solutions (33).

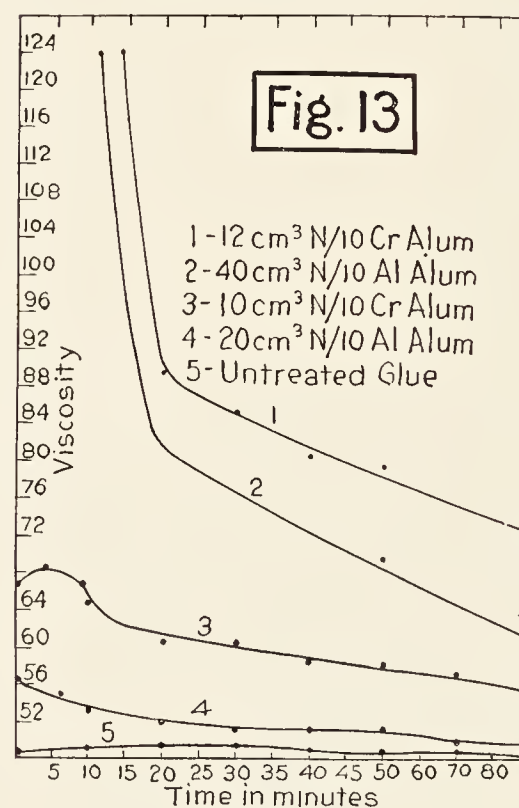
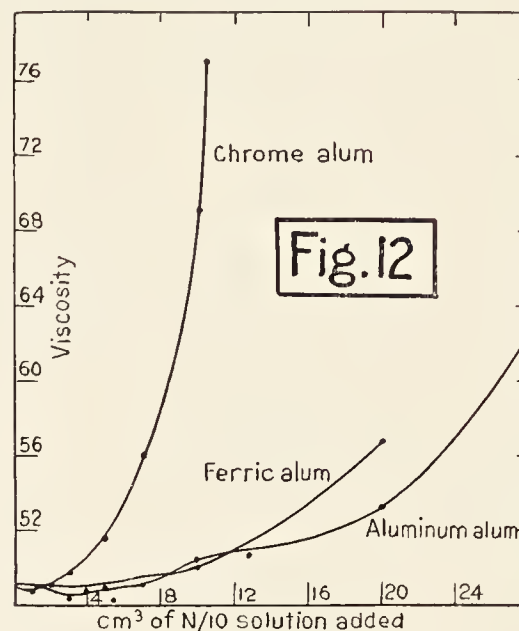
#### Gelling point

The gelling point of a glue is the temperature at which appreciable flow under the action of gravity ceases.

Chrome alum (anhydrous salt = 0.8% wt. of dry glue) raises the setting or gelling point *ca.* 2°C with 20% glue solutions and *ca.* 10° with 50% glue solutions. The gelling points (in °F on curves) of glue solutions as affected by addition of chrome alum are shown in Fig. 21 (33).

#### Drying Behavior

High grade liquid glues lose water much more slowly than low grade glues when dried at room temperatures (2).



## 2. GELATINS

### Jelly Strength

Alcohol up to *ca.* 25 vol. % tends to increase the rigidity of 10% gelatin gels; larger amounts cause a decrease. Acetone acts similarly (20).

According to Bogue (15) the maximum jelly strength occurs at pH = *ca.* 4, and minimum at pH = *ca.* 5, near the isoelectric point. Sheppard and Sweet (27) find the maximum at the isoelectric point, pH = 4.7, with a minimum at pH = *ca.* 5.5 and a second maximum at pH = 7.8.

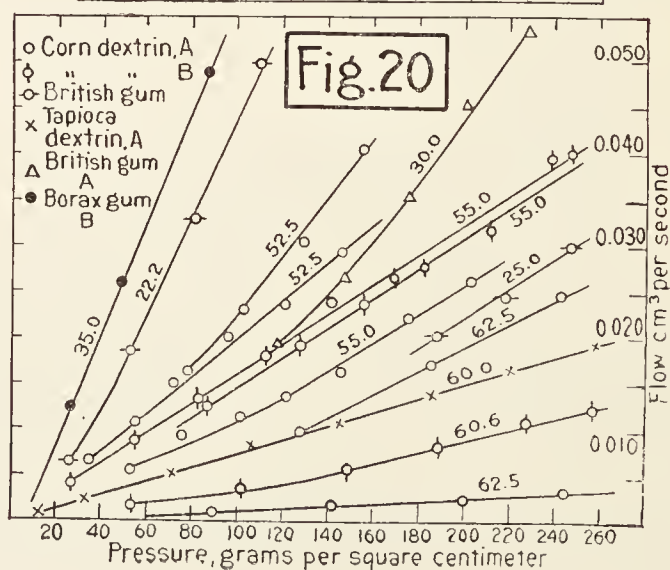
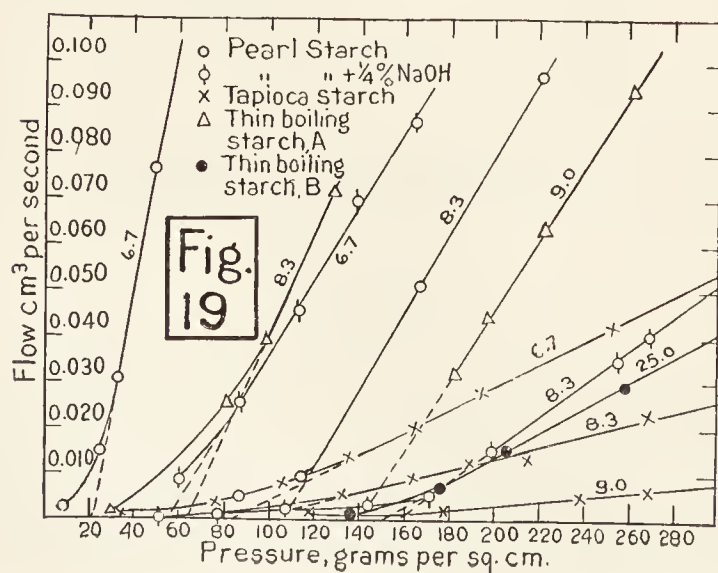
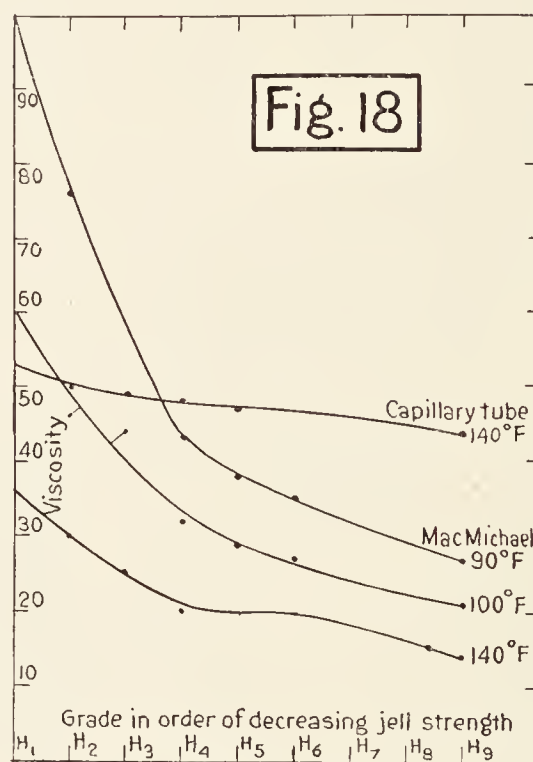
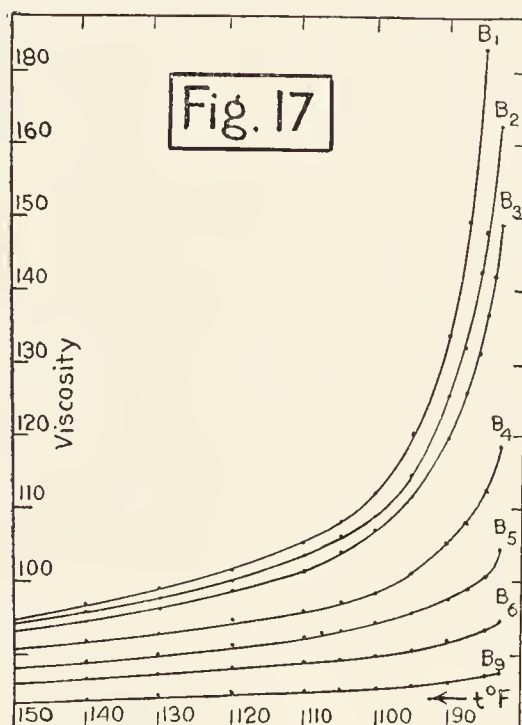
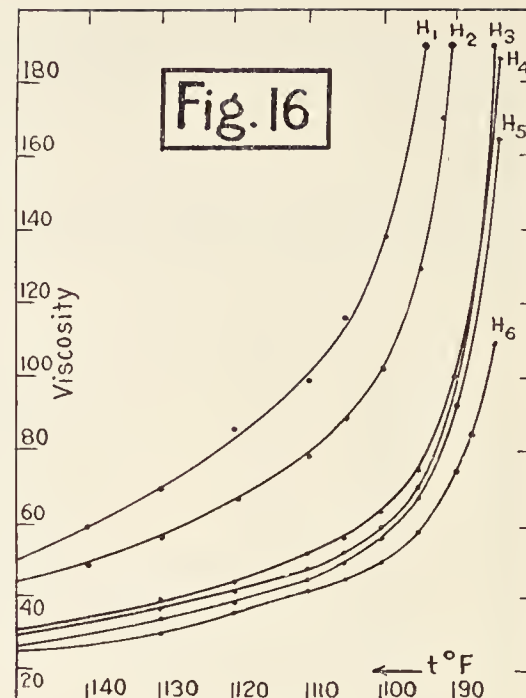
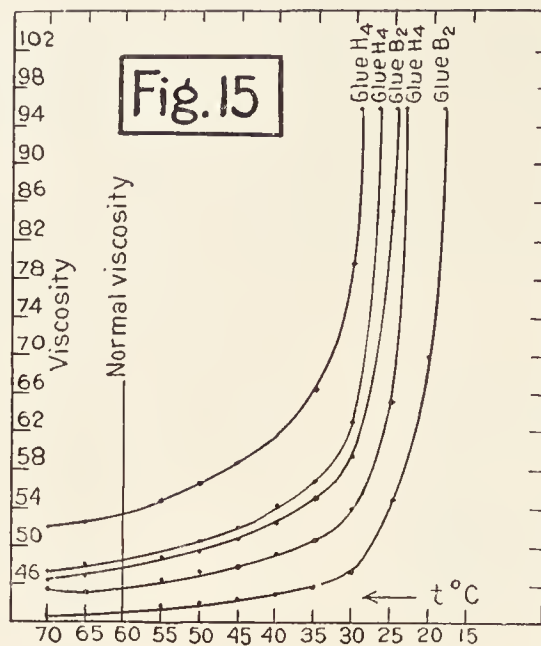
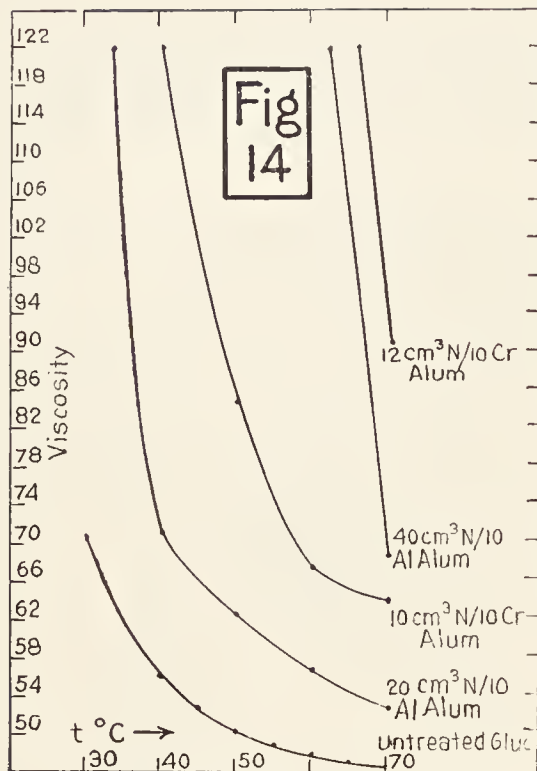
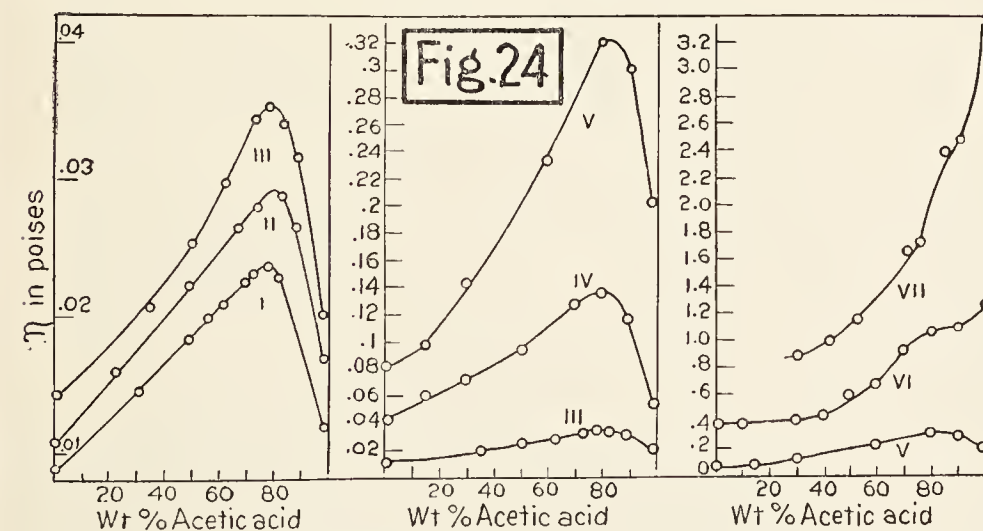
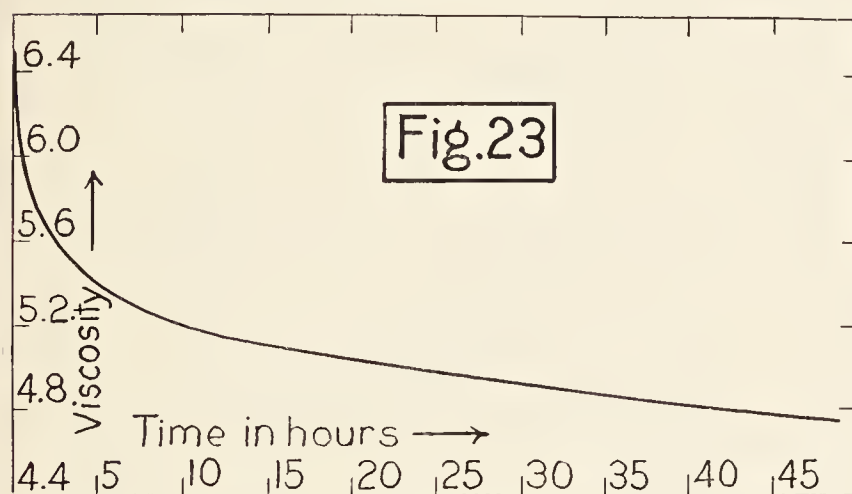
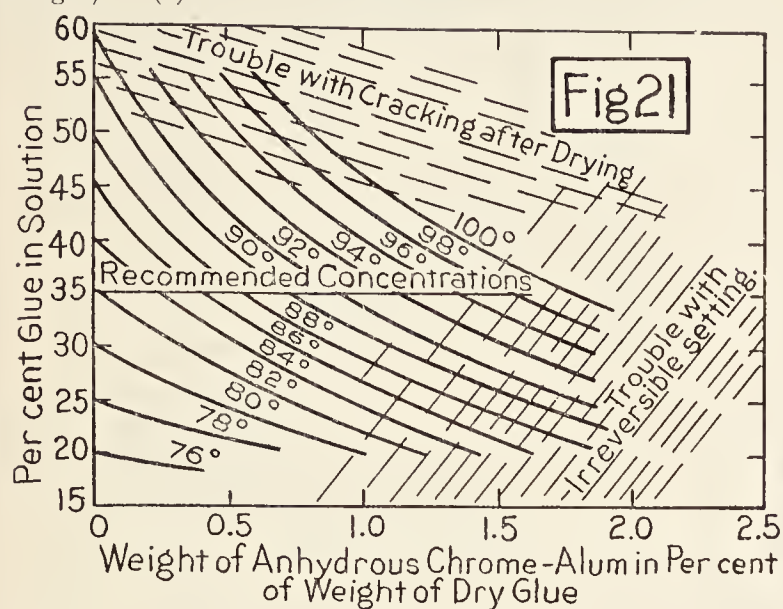




Figure 22 shows the influence of traces of Al salts on the rigidity of a 7% gelatin jelly (28).

For the effect of sulfuric, phosphoric and lactic acids on jelly strength, see (4).



Adhesive Strength

Slight hydrolysis increases the adhesive strength of high-grade gelatin, while continued hydrolysis decreases it (13).

Viscosity

Gelatin in aqueous solution, as measured by the MacMichael viscometer, follows the laws of viscous flow at temperatures above *ca.* 40°C, but exhibits the properties of plastic flow below the solidification point. The sol-gel transformation occurs over

a range rather than at a point. At 35°C, time rate of change of  $\eta$  varies with the pH of the solution, the concentration and nature of inorganic ions, and the amount of hydrolyzed protein present (3).

Figure 23 shows the variation of  $\eta$  at 35°C (in arbitrary units) with time for a 5% purified photographic gelatin, pH = 4.9 (18).

The  $\eta$  at 25°C of solutions of gelatin in aqueous acetic acid is given in Fig. 24. Curve (1) is for the two liquids alone, (2) for 0.2 g gelatin per 100 cm<sup>3</sup> of solution, (3) for 0.6 g, (4) for 5 g, (5) for 10 g, (6) for 15 g, (7) for 20 g per 100 cm<sup>3</sup> (20).

The  $\eta$  at 25°C of solutions of gelatin (10 g per 100 cm<sup>3</sup>) in formamide + water and formamide + acetic acid is given in Fig. 25. The dotted curves are the  $\eta$  of the mixtures without the gelatin (20).

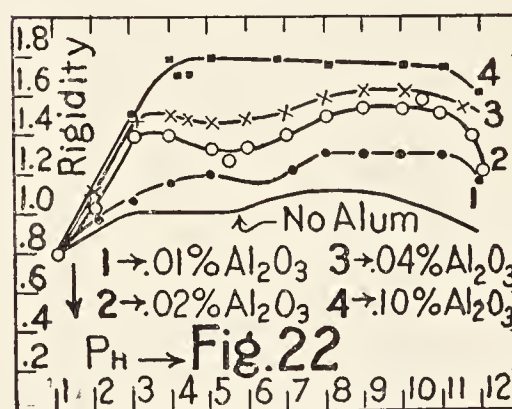
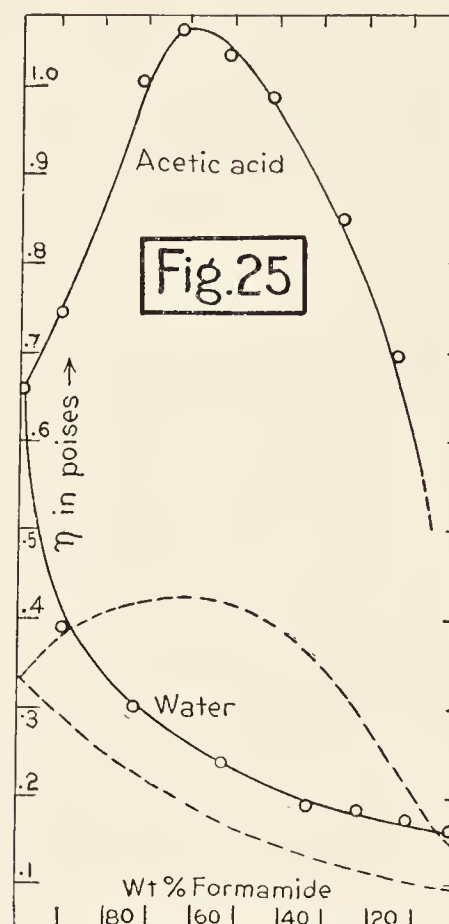


Figure 26 shows the  $\eta$  at 28°C of solutions of gelatin (5 g per 100 cm<sup>3</sup>) in methyl alcohol-water mixtures. A =  $\eta$  of fresh solution; B =  $\eta$  after 30 min (20).

Figure 27 shows  $\eta$  at 30°C of solutions of gelatin (15 g per 100 cm<sup>3</sup>) in methyl alcohol-water mixtures. A = freshly prepared; B = after 15 min (20).

Figure 28 gives  $\eta$  at 25°C of solutions of gelatin (2 g per 100 cm<sup>3</sup>) in ethyl alcohol-water mixtures. A = freshly prepared; B = after 30 min (20).

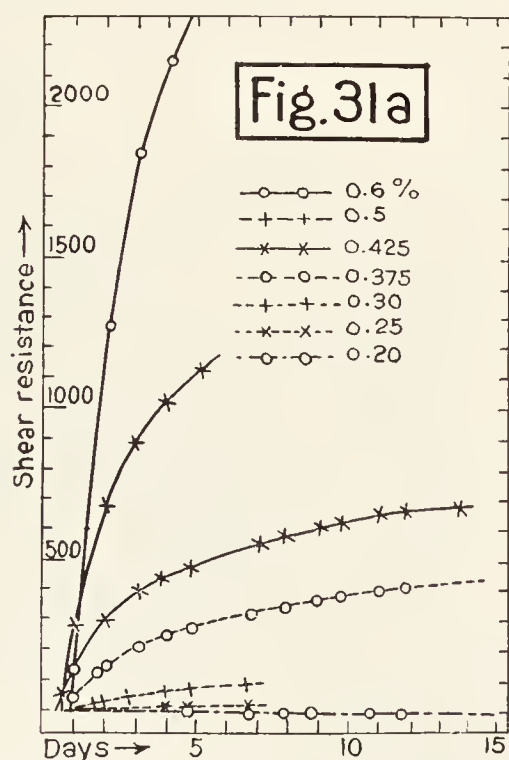
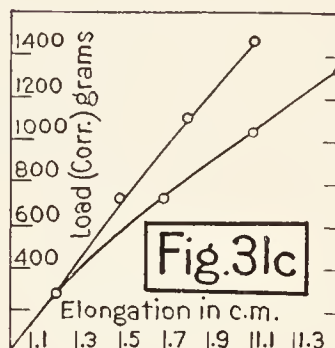
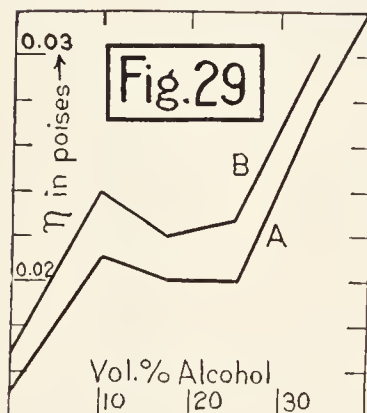
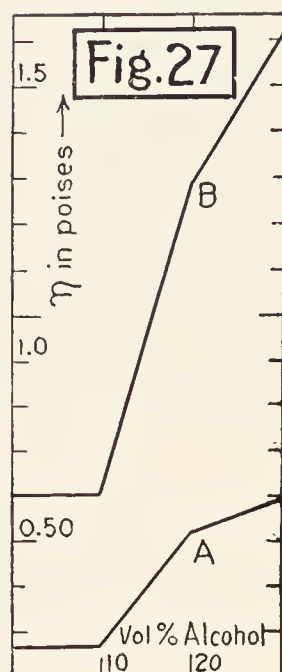
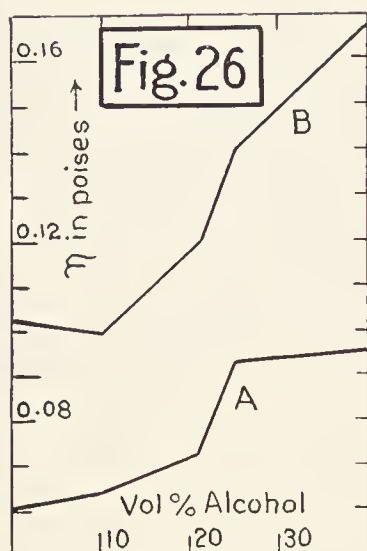


Figure 29 gives  $\eta$  at 30°C of solutions of gelatin (10 g per 100 cm<sup>3</sup>) in ethyl alcohol-water mixtures. A = freshly prepared; B = after 30 min (20).

Figure 30 gives  $\eta$  at 35°C of solutions of gelatin (10 g per 100 cm<sup>3</sup>) in acetone-water mixtures (20).

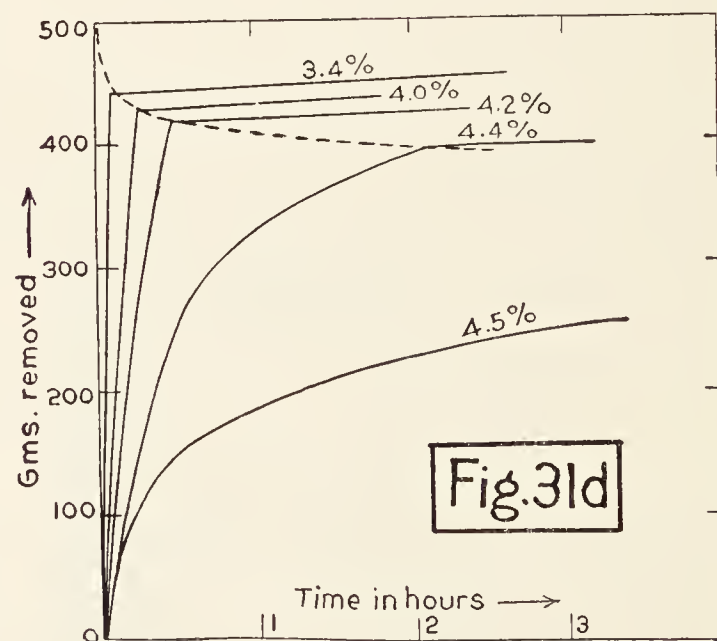
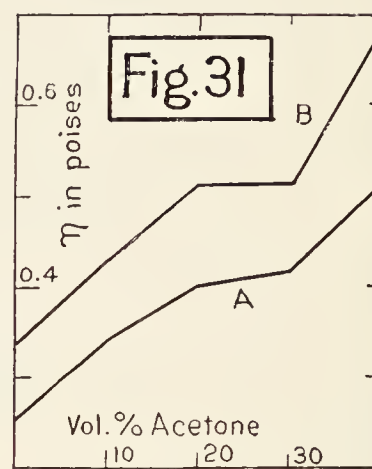
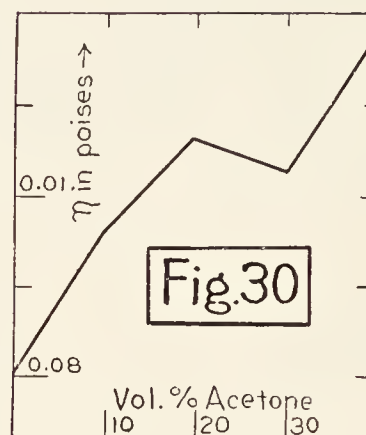
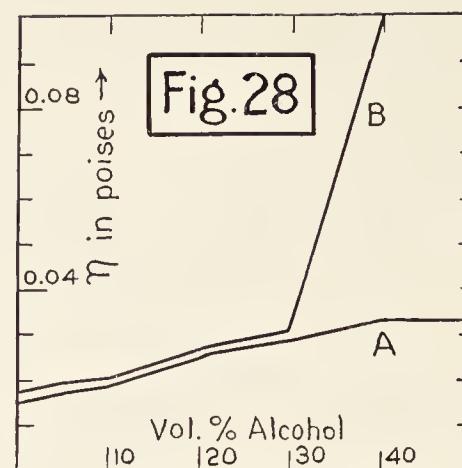


Figure 31 gives  $\eta$  at 30° of solutions of gelatin (15 g per 100 cm<sup>3</sup>) in acetone-water mixtures. A = freshly prepared; B = after 15 min (20).

The addition of pyridine to solutions of gelatin in water increases  $\eta$ , while addition of dimethylamine and diethylamine up to ca. 25 wt. % of solution decreases, and over 30 % again increases  $\eta$  (20) cf. (45, 46, 47).

#### Plasticity and Elasticity

The temperature at which plasticity appears in gelatin solutions depends both on the concentration and on the way in which the solution is prepared (49).



Figure 31a gives the change with time of the elastic resistance to shear of dilute gelatin solutions (0.2–0.6%) at 8°C (50).

Figures 31b and 31c show the behavior of gelatin jellies under torsion and stretch, respectively. The gelatin content of the jellies is given in wt. % (51).

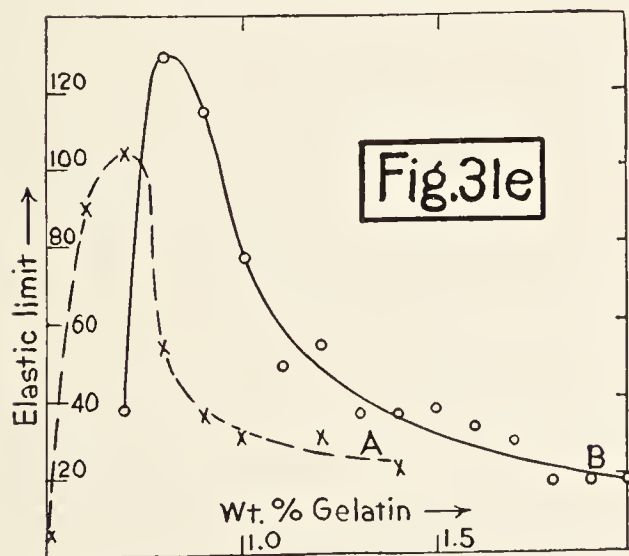
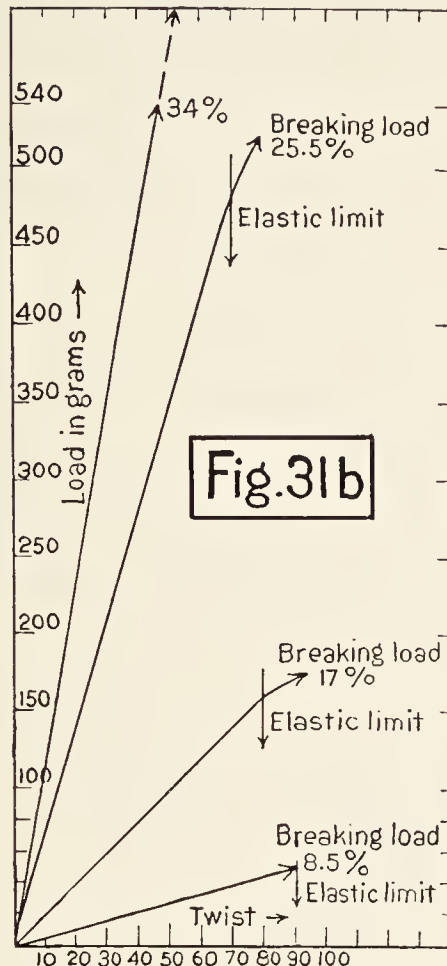


Figure 31d shows the behavior of gelatin jellies (3.4–4.5 wt. % gelatin) which have been under a load of 500 g at 16.5°F. The portion of the load removed in order to keep the deformation constant is given as a function of time (52).

Figure 31e shows the relation between the elastic limit of gelatin solutions and the concentration of the gelatin in the solution. A = purified gelatin; B = a commercial gelatin.

#### Surface Tension; $\gamma$

Figure 32 shows the variation in the drop-weight of water solutions of ossein gelatin with varying concentrations of gelatin (13).

Figure 33 shows the variation of drop weight of gelatin-water solutions with temperature, and Fig. 34 with pH (13).

Figure 35 shows the effect of pH on the drop weight of various gelatin-water solutions containing 0.5% gelatin (13).

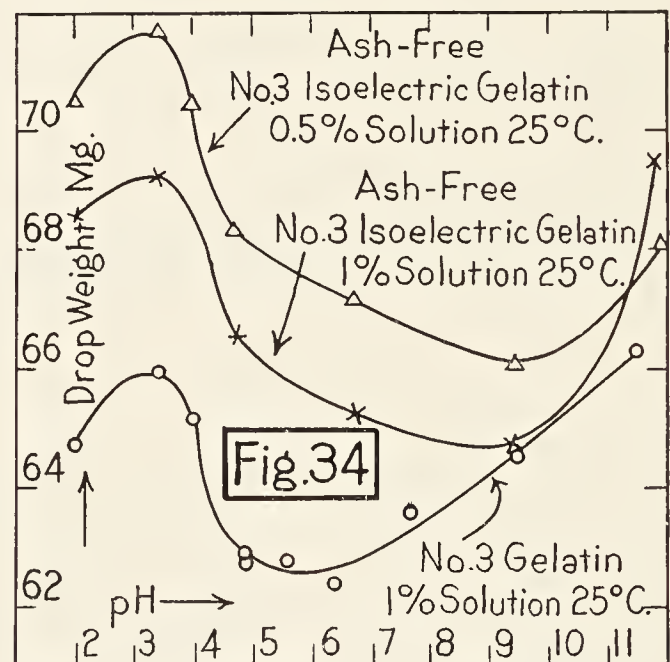
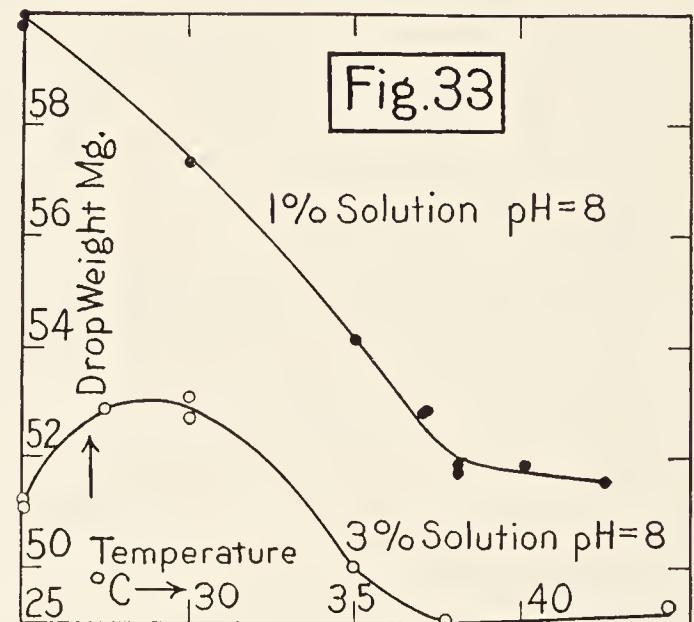
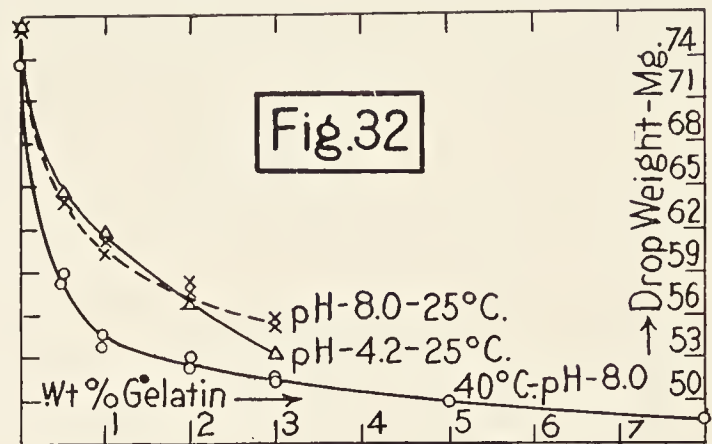


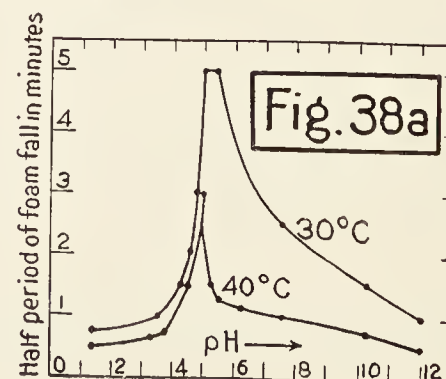
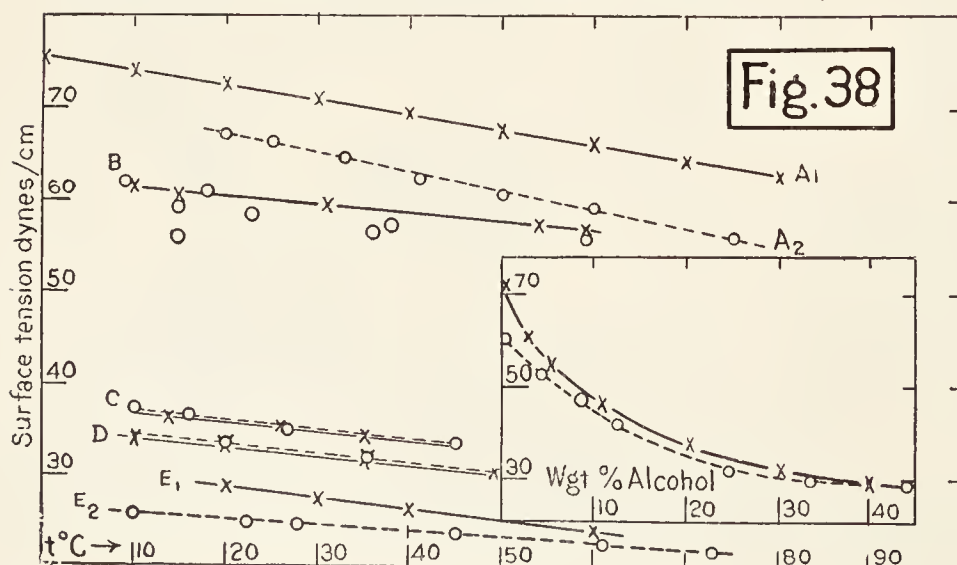
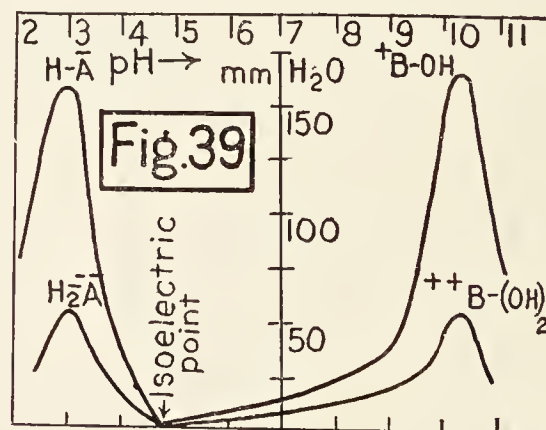
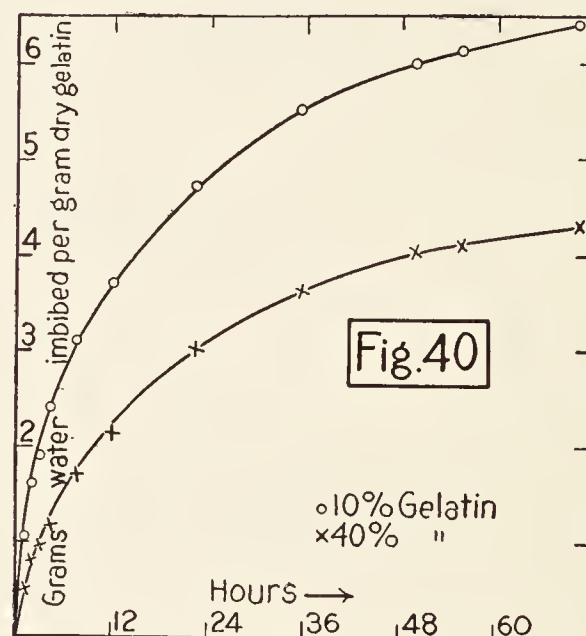
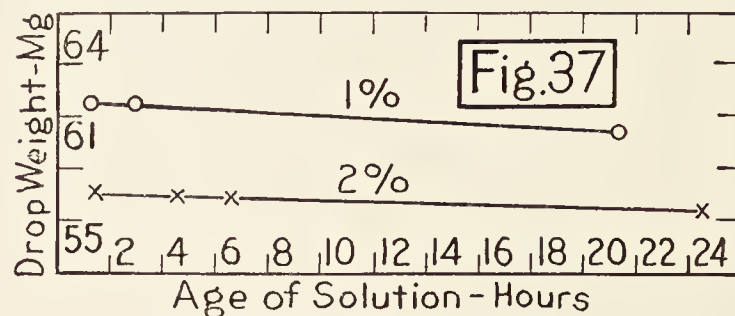
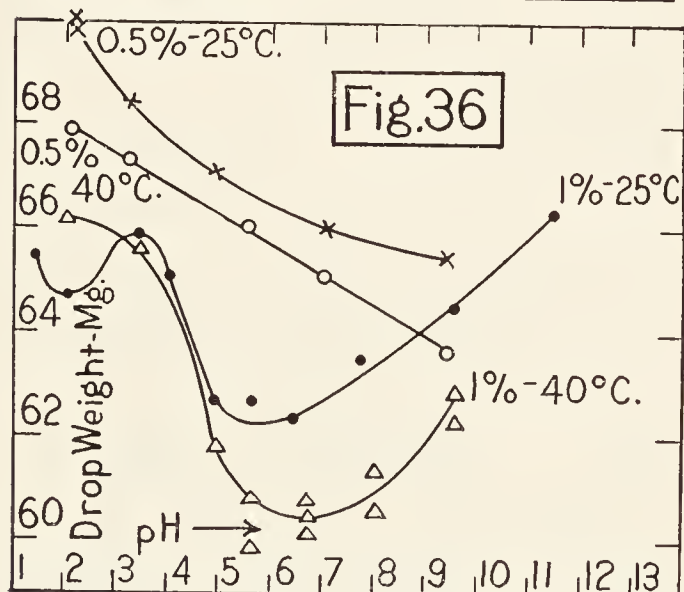
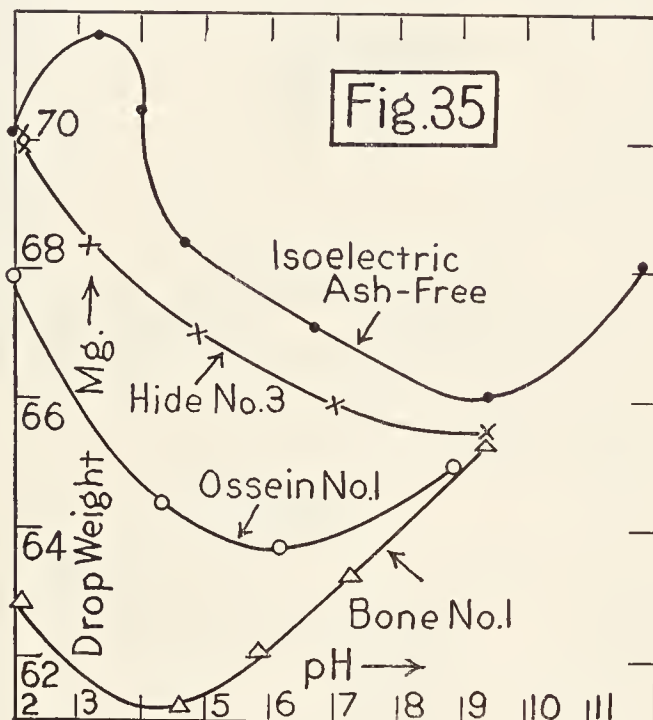
Figure 36 shows the effect of pH on a hide gelatin (0.5 and 1 wt. % of gelatin) solution in water at 25° and 40°C (13).

Figure 37 gives the variation in drop weight of 1 and 2% gelatin in water solutions with time (13).

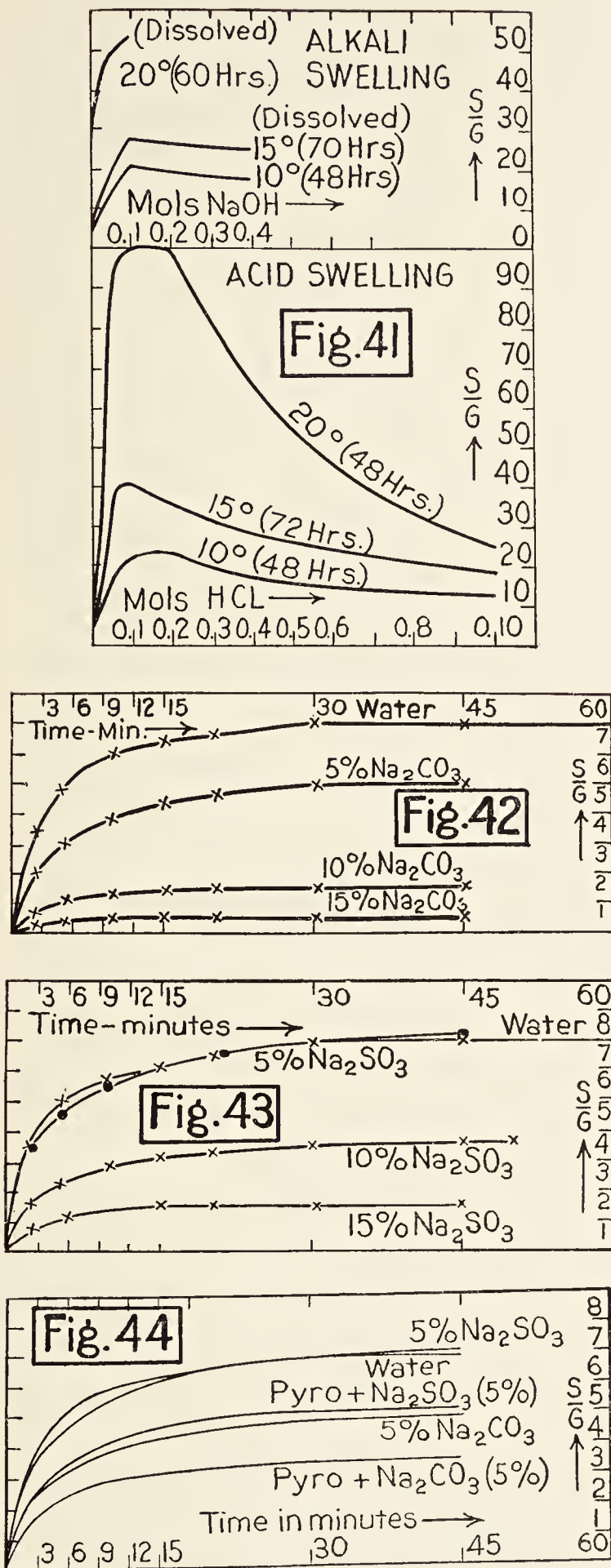
Figure 38 (20) shows the variation of  $\gamma$  with temperature for various gelatin solutions.  $A_1$  = pure  $H_2O$ .  $A_2$  = 5 g gelatin per 100 cc water solution.  $B$  = pure formamide (same for 5 g gelatin per 100 cc formamide solution).  $C$  = phenol-acetic acid mixture (dotted line gives values of  $\gamma$  after addition of gelatin, 5 g per 100  $cm^3$  of mixture).  $D$  = *o*-cresol-acetic acid mixture (dotted line

after addition of 5 g gelatin per 100  $cm^3$  of mixture).  $E_1$  = pure acetic acid.  $E_2$  = pure acetic acid + 5 g gelatin per 100  $cm^3$ . The inset gives  $\gamma$  for water-alcohol solutions of gelatin against temperature. Solid curve for mixtures of alcohol-water. Dotted curve for mixtures with 10 g gelatin per 100  $cm^3$  solution.

Two per cent gelatin solutions at 30°C by stalagmometer show a rise in  $\gamma$  to a maximum at pH = 8-9, falling to a minimum at pH = 4.5 and rising to a lower maximum at pH = 3 (12).







See (54) for  $\gamma$  between toluene and gelatin solutions.

Figure 38a shows the relation between pH and foam on aqueous gelatin solutions,  $\gamma$  for the solution being smallest at the isoelectric point where the foam is most stable.

#### THERMAL EXPANSION Aqueous solutions of gelatin (37)

Wt. % gelatin.....	0.0	2.02	5.04	8.9	10.4	16.5	24.8
$\frac{10^6 \Delta V}{V \Delta t}$ (15°-32°C).....	241	249	267	289	300	341	386

Wt. % gelatin.....	0.0	3.60	7.05	13.00
Temp. of max. density.....	+4.0°	+2.5°	+1.3°	-1.2°

#### Osmotic Pressure

Figure 39 gives the osmotic pressure at 10°C of 0.5 g gelatin per 100 cm<sup>3</sup> water solution against solutions of acids and bases of pH value indicated (29).

#### Swelling and Contractility

Figure 40 shows the swelling behavior of dry gelatins when immersed in pure H<sub>2</sub>O for the times indicated. The 10% gel was prepared by drying a solution made from 90 g H<sub>2</sub>O + 10 g gelatin and the 40% gel from a solution of 60 g H<sub>2</sub>O + 40 g gelatin, the dried pieces being of the same area and thickness (15).

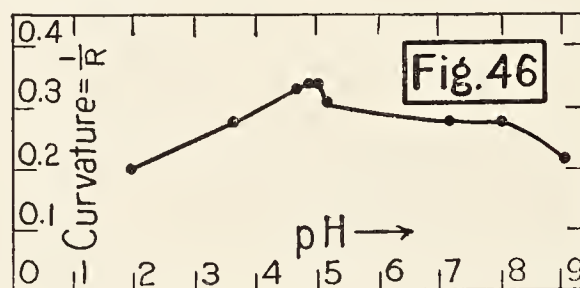
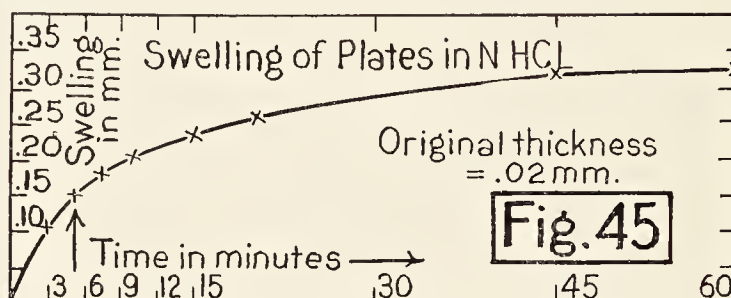


Figure 41 shows the influence of temperature, S/G = grams H<sub>2</sub>O imbibed per gram gelatin (25).

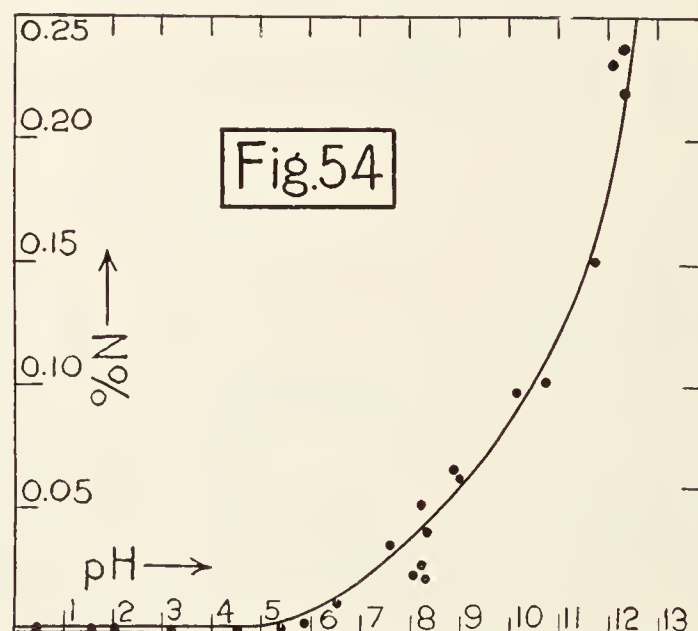
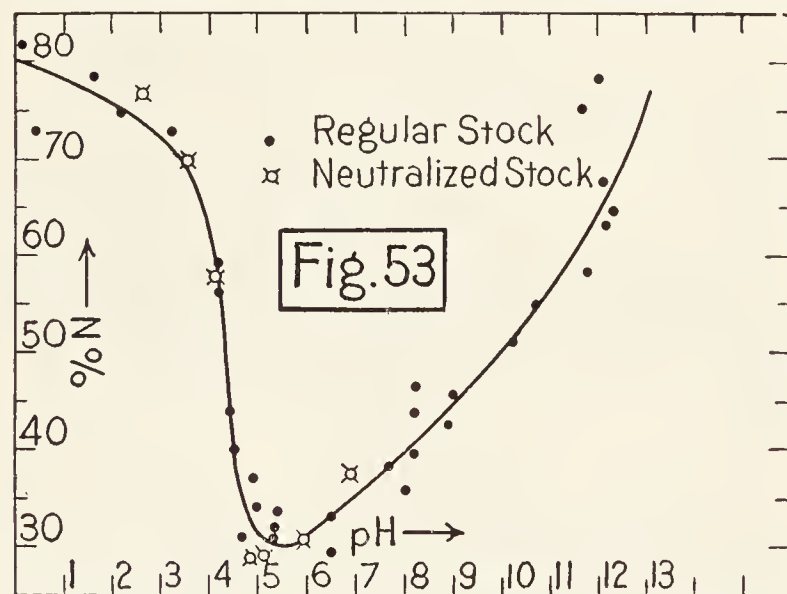
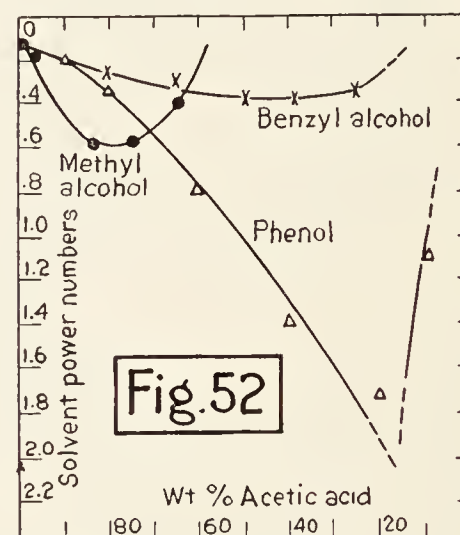
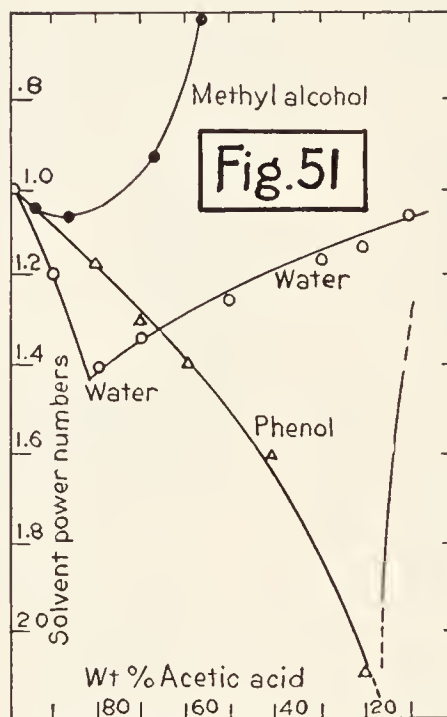
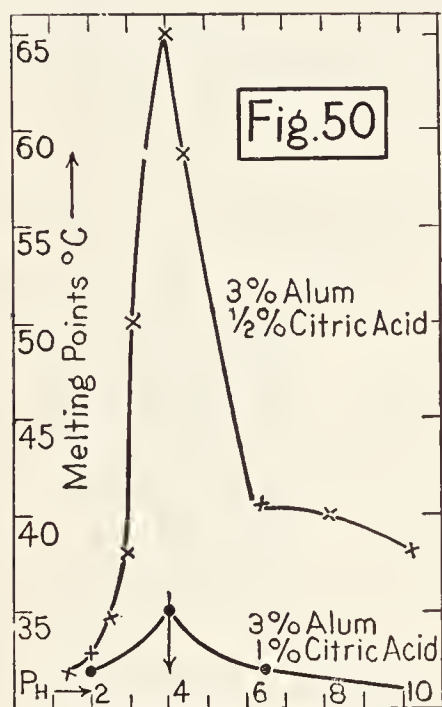
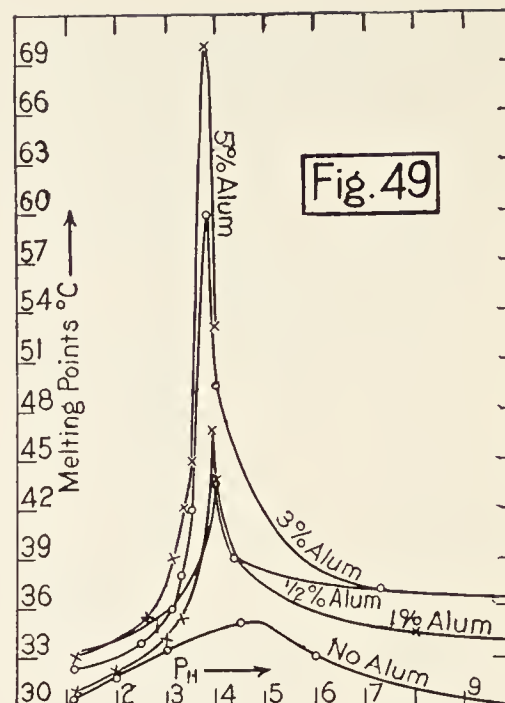
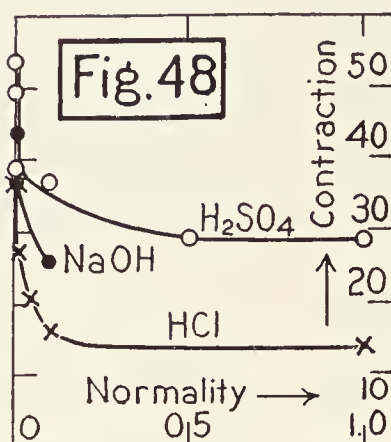
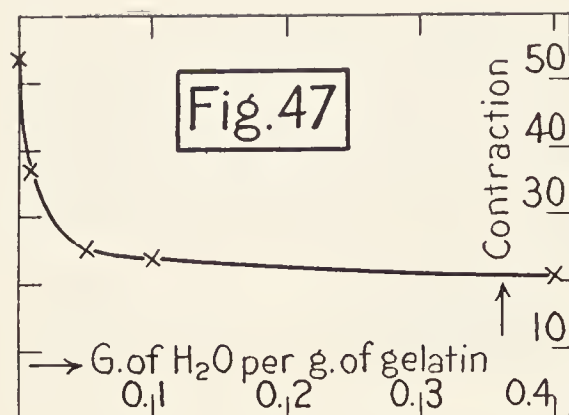
Figures 42, 43, 44, and 45. Silver bromide emulsion gelatin on plates when immersed in the solutions indicated for varying times (25).

The following table and Fig. 46 show the contractility of gelatin films as measured by the curvature produced in thin Al discs coated on one side with 10% gelatin solution and dried under uniform conditions. In Fig. 46, the gelatin films were prepared from de-ashed material, in solutions of the pH indicated (26).

#### CONTRACTILITY

Gelatin	Radius in cm	Curvature 1/R	Remarks
Commercial hard A..	24	0.041	{ Good grade photographic gelatins
Commercial hard B..	24.5	0.0405	
Ossein gelatin.....	26	0.038	Photographic quality
Hide gelatin No. 6902	31	0.032	Good grade hide gelatin
Same, de-ashed.....	31	0.032	Ash less than 0.01%
Sizing gelatin.....	34	0.029	Poor grade

There is no definite relation between the contractility of gelatins and their swelling on immersion in H<sub>2</sub>O, indicating that there are individual structural differences in gelatins, depending not simply on physico-chemical conditions but on origin and previous history (26).



Gelatin shows two points of minimum swelling with change in pH, one at pH = 4.7 and the other at pH = 7.7 (41).

For the swelling of gelatin in solutions of polybasic acids and their salts, see (42).

Figure 47 shows the contraction in mm<sup>3</sup> per g. of gelatin on dissolving in 100 cm<sup>3</sup> of H<sub>2</sub>O as a function of the H<sub>2</sub>O content of the gelatin before dissolving, and Fig. 48 shows the contraction on dissolving a gelatin of constant H<sub>2</sub>O content in 100 cm<sup>3</sup> of acid or alkali of varying normality (31).

The swelling of gelatin gels shows a maximum at pH = 3-3.5 and a minimum at pH = 5 (4). For effects of certain solutes in increasing swelling *v.* (36).

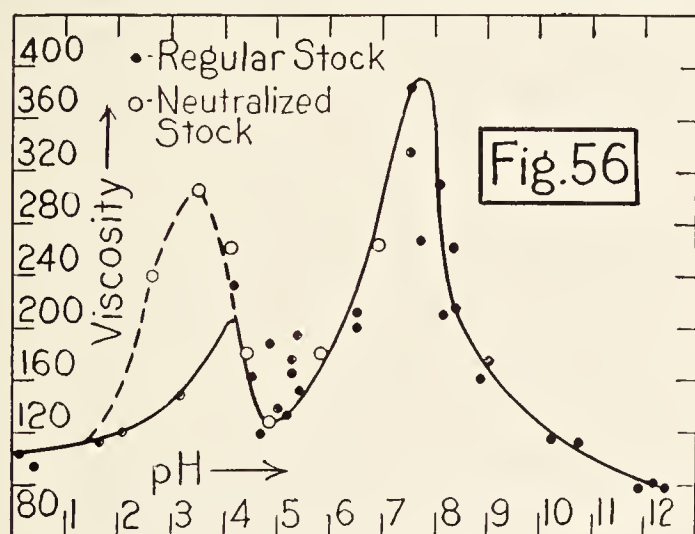
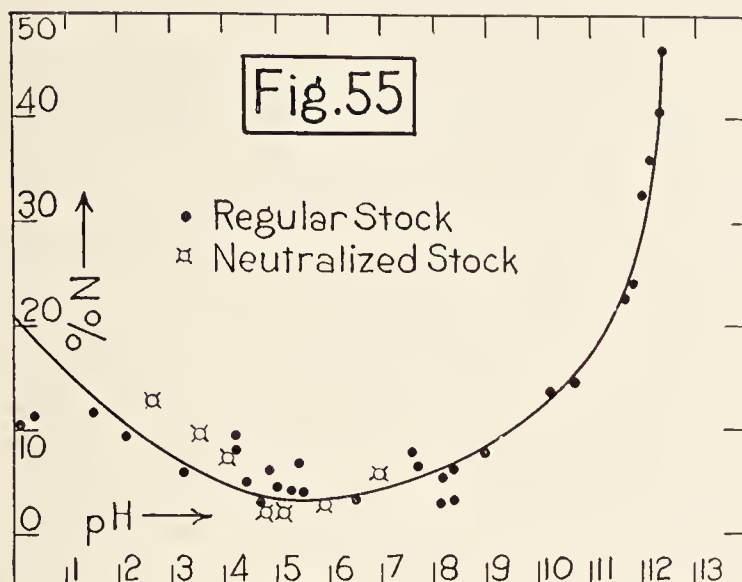
Gelatin gels show a minimum resistance to stretch at pH = 4.7 and a maximum at pH = 3 and 11 (24).



## Melting Point

Figure 49 shows the "M. P." of gelatins, prepared with different pH values, as determined after immersion for a constant time in alum solutions of the concentrations indicated (25).

Figure 50 shows the "M. P." of gelatins, prepared with different pH values, as determined after immersion for a constant time in alum solutions with 0.5 and 1.0% of citric acid (25).



Solubility in H<sub>2</sub>O

<0.01 wt. % at room temp. (17, 18).

Parts ‰. 22°C, 1; 18.3°, 0.7; 15-17°, 0.5; 0°, 0.2 (35).

## Solvent Power Numbers

The solvent power number is the relative volume of a liquid required to start the precipitation of gelatin from a solution containing 15 g gelatin per 100 cm<sup>3</sup>, upon mixing at 25°C.

Figure 51 shows the solvent power numbers for acetone on solutions of gelatin in acetic acid mixtures and Fig. 52 the same values for xylene (20).

## Hydrolysis of Collagen to Gelatin (6)

The experiments covered by the following figs. were carried out on well limed hide pieces for periods of 8 hr unless otherwise indicated and exhibit the effect of the pH during hydrolyzing on the factors named:

Fig. 53. On the % of total N recovered in the solution.

Fig. 54. On the % of N evolved as NH<sub>3</sub>.

Fig. 55. On the % of amino acid N recovered in the solution.

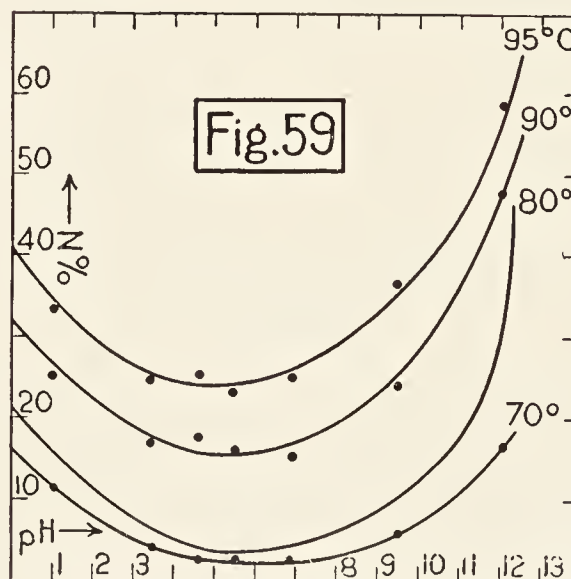
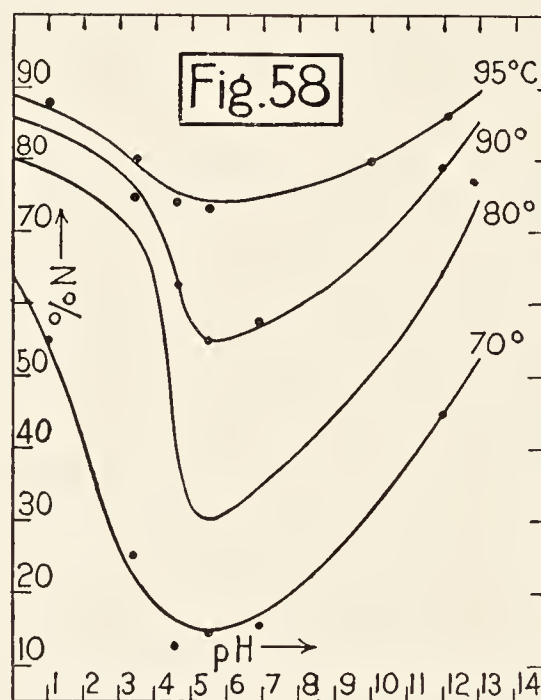
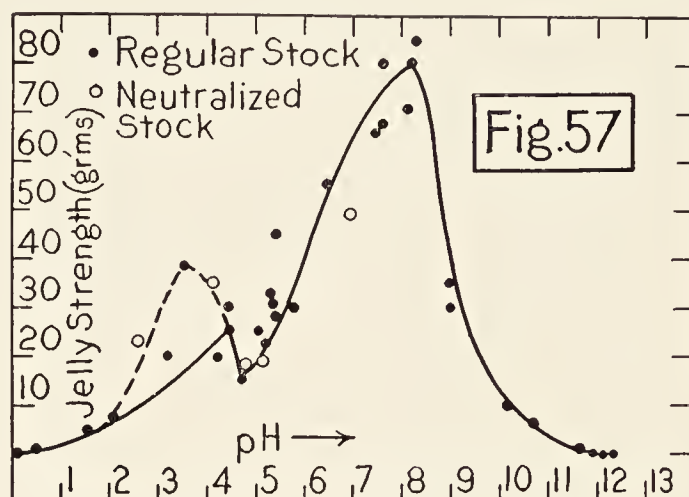
Fig. 56. On the viscosity (in arbitrary units) of the product at 35°C.

Fig. 57. On the jelly strength of the product at 10°C.

Fig. 58. On total N recovered in the solution after hydrolyzing at temperatures indicated.

Fig. 59. On amino acid N in the solution after hydrolyzing at temperatures indicated.

Fig. 60. On the total N recovered and Fig. 61 on the amino acid N, in the solution after hydrolyzing at 80°C for times indicated.



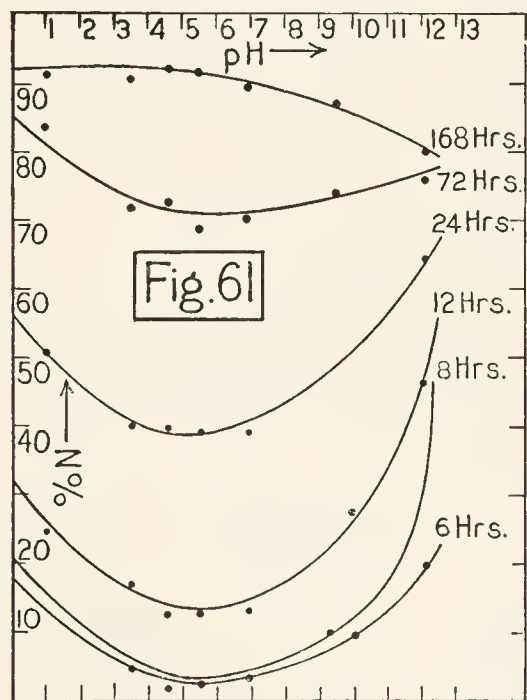
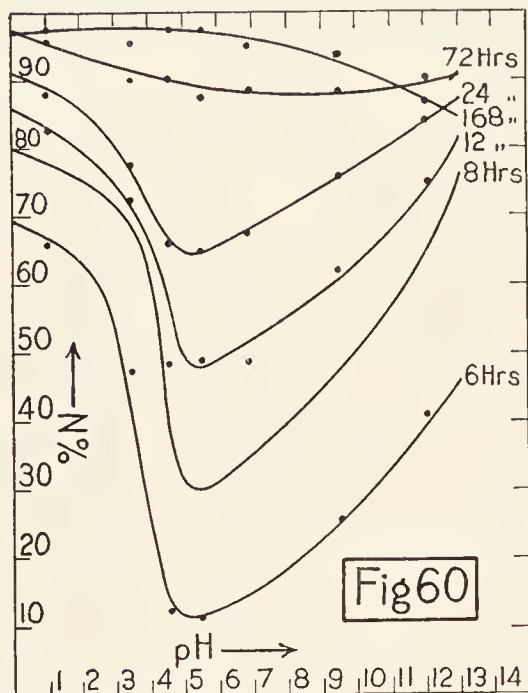
## Mutarotation

The change in specific rotation (mutarotation) of gelatin solutions of constant concentration, upon reducing the temperature from 35° to 15°C, decreases very rapidly with decreasing jelly consistency of the gelatin or glue (4). See also (17, 35, 48).

## Electrical Conductivity

The conductivity of gelatin solutions in water is a useful criterion of the purity of the gelatin. The purest solutions which have been prepared have the same conductivity as pure water (38).

See (39) for the conductivity of some gelatin and glutin solutions.



## Miscellaneous

For the extraction of gelatin from bones as a function of temperature and time, see (19).

Figure 62 shows the influence of pH on the alcohol number, turbidity, and foam of gelatin solutions (4).

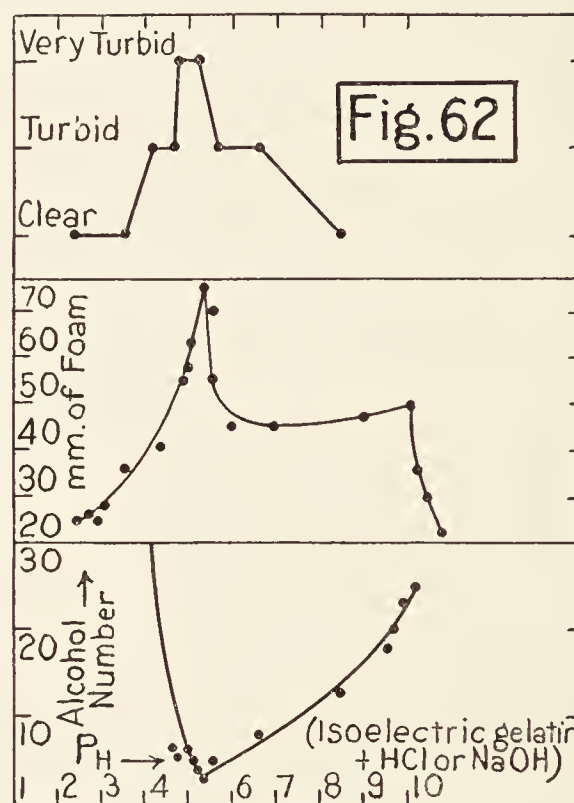
A method of determining the gelling power of gelatins is given in (43).

For the liquefaction of gelatins by salt solutions, see (44).

## LITERATURE

(For a key to the periodicals see end of volume)

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- (30) Stiasny, *55*, **35**: 353; 24. (31) Svedberg, *1*, **46**: 2673; 24. (32) Tressler, *45*, **16**: 943; 24. (33) Wilson and Ross, *45*, **15**: 367; 22. (34) Wislicenus and Lorenz, *55*, **34**: 207; 24. (35) Fairbrother and Swan, *4*, **122**: 1239; 22. (36) Popoff and Seioff, *205*, **156**: 97; 25. (37) Taffel, *4*, **121**: 1971; 22. (38) Rockefeller Institute, New York City, O. (39) Wintgen and Vogel, *55*, **30**: 45; 22. (40) Thiele, *Leim und Gelatin*. 2nd ed. Leipzig, Jaenecke, 1914. (41) Wilson and Kern, *1*, **44**: 2633; 22. (42) Fischer and Hooker, *1*, **40**: 857; 18. (43) Smith, *45*, **12**: 878; 20. (44) Briggs and McHieber, *50*, **24**: 74; 20. (45) Oakes and Davis, *45*, **14**: 706; 22. (46) Davis, Oakes and Browne, *1*, **43**: 1526; 21. (47) Bogue, *1*, **43**: 1764; 21. (48) Smith, *1*, **41**: 135; 19. (49) Sheppard, *50*, **29**: 1224; 25. (50) Rohloff and Shinjo, *63*, **8**: 442; 07. (51) Sheppard and Sweet, *1*, **43**: 540; 21. (52) Rankine, *3*, **11**: 447; 06. (53) Freundlich and Seifriz, *7*, **104**: 233; 23. (54) Sheppard and Sweet, *1*, **44**: 2797; 22. (55) Sheppard, *Third Colloid Symposium Monograph*. New York, Chem. Cat. Co., 1925. (56) *Second Report of the Adhesives Research Committee* (Dept. of Sci. Ind. Research, London, 1926) contains valuable information on adhesive action, glue, gelatin, etc.



## TEXTILE FIBERS

J. MERRITT MATTHEWS

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## BOTANICAL CLASSIFICATION OF IMPORTANT VEGETABLE FIBERS

- (A) Vegetable hairs.
1. Cotton (seed-hairs of *Gossypium* sp.).
  2. Bombax cotton (fruit-hairs of *Bombacæ*).
  3. Vegetable silks (seed-hairs of various *Asclepiadacæ* and *Apocynacæ*).
- (B) Bast fibers from the stalks and stems of dicotyledonous plants.
- (a) Flax-like fibers.
4. Flax (*Linum usitatissimum*).
  5. Hemp (*Cannabis sativa*).
  6. Gambo hemp (*Hibiscus cannabinus*).
  7. Sunn hemp (*Crotalaria juncea*).
  8. Queensland hemp (*Sida retusa*).
  9. Yercum fiber (*Calotropis gigantea*).
- (b) Boehmeria fibers.
10. Ramie or China grass (*Boehmeria nivea*).
- (c) Jute-like fibers.
11. Jute (*Corchorus capsularis* and *C. olitorius*).
  12. Raibhenda (*Abelmoschus tetraphyllos*).
  13. Pseudo-jute (*Urena sinuata*).
- (d) Coarse bast fibers.
14. Bast fibers from *Bauhinia racemosa*.
  15. Bast fibers from *Thespesia lampas*.
  16. Bast fibers from *Cordia latifolia*.
- (e) Basts.
17. Linden bast (*Tilia* sp.).
  18. Bast from *Sterculia villosa*.
  19. Bast from *Holoptelea integrifolia*.
  20. Bast from *Kydia calycina*.
  21. Bast from *Lasiosyphon speciosus*.
  22. Bast from *Sponia Wightii*.

- (C) Vascular bundles from monocotyledonous plants.
- (a) Leaf fibers.
23. Manila hemp or abaca (*Musa textilis* and others of this kind).
  24. Pita (*Agave americana* and *A. mexicana*).
  25. Sisal (*Agave rigida*).
  26. Mauritius hemp (*Agave fatida*).
  27. New Zealand flax (*Phormium tenax*).
  28. Aloe fibers (*Aloë* sp.).
  29. Bromelia fibers (*Bromelia* sp.).
  30. Pandanus fibers (*Pandanus* sp.).
  31. Sansevieria fibers (*Sansevieria* sp.).
  32. Esparto fibers (*Stipa tenacissima*).
  33. Piassave (*Attalea funifera*, *Raphia vinifera*, etc.).
- (b) Stem fibers.
34. Tillandsia fibers, southern moss (*Tillandsia usneoides*).
- (c) Fruit fibers.
35. Coir or coconut fiber (*Cocos nucifera*).
  36. Peat fibers.
- (d) Paper fibers.
37. Straw fibers (rye, wheat, oat, rice).
  38. Esparto fibers (leaf fibers of *Stipa tenacissima*).
  39. Bamboo fibers (*Bambusa* sp.).
  40. Wood fiber (pine, fir, aspen, etc.).
  41. Bast fiber from paper mulberry (*Broussonetia papyrifera*).
  42. Bast fiber from *Edgeworthia papyrifera*.
  43. Peat fibers.
- (Wiesner, *Die Rohstoffe des Pflanzenreiches*)

## MICROSCOPICAL CHARACTERISTICS OF IMPORTANT VEGETABLE FIBERS

Fiber	Microscopical appearance
Cotton.....	Appears as a flat, ribbon-like band, more or less twisted on its longitudinal axis. Twist of fiber not continuous in one direction; cell-walls thick; lumen breadth much thicker than cell-wall; between thickened edges fiber shows finely granulated surface. Diameter uniform for $\frac{3}{4}$ length, then tapers to a point where it is cylindrical and solid
Flax.....	Cylindrical tapering to sharp point; cell-wall so thick that lumen appears as thread; fine cross-lines at intervals give appearance of joints or nodes, sometimes intersecting like letter X
Hemp.....	Lumen is broad, equaling or exceeding the thickness of the walls. Pronounced longitudinal striations. Ends of fibers blunt and thick-walled, often with lateral branches. Dislocations or folds; also swellings and cross-fissures. Fibers less transparent than flax and canal more difficult to distinguish
Jute.....	Lumen irregular, at times as wide as or wider than cell-wall; at ends of fiber lumen broadens out; end round. Longitudinal striations, no transverse markings, no jointed ridges
Manila hemp (abaca)	Lumen broad, distinct and uniform; cell-wall thin; ends narrow and sharp; no markings; diameter uniform
Manila hemp, sisal or Domingo hemp.	Fibers usually very stiff, and become very broad toward middle; have broad lumen, broad, blunt, thick ends, which are seldom forked. Short thick-walled cells are abundant, and show a narrow lumen and distinct surface pores. Peculiar spiral and parenchyma cells are often present
Straw.....	Bast cells are long thin fibers of regular structure with small canal; very slender and taper to fine point. Epidermal cells are thick-walled, short, broad, serrated. Parenchyma cells thin-walled and shaped like coffee bean
Esparto.....	Cells smaller than, but very similar to, straw cellulose. Esparto does not have the thin-walled bean-shaped cells, but has very small characteristic pear-shaped cells. Bast cells have numerous cross-markings
Ramie.....	Bast cells very long and broad, diameter very irregular; base very irregular; lumen, sometimes quite distinct, and sometimes disappearing entirely; fibers show numerous joints and transverse fissures; ends of fibers form a thick-walled, rounded point, and the lumen is reduced to a line
New Zealand flax.	Fiber elements, or cells, are usually very regular and uniform, surface is smooth in general. Lumen is usually narrower than cell-wall and very uniform in width. Ends are sharply pointed, and not divided. Fragments of parenchyma and epidermis can often be seen on the fibers
Pita fiber.....	Fiber is stiff and short, has a rather thin wall. Fiber has a distinctive wavy appearance and is very elastic. Very similar to sisal hemp in microscopical appearance

Fiber	Microscopical appearance
Pineapple leaf fiber.	Fiber very fine and has great durability. Lumen narrow and appears like a line. This fiber is distinguished from all other leaf fibers by its extreme fineness
Coniferous wood fibers.	Fibers from coniferous trees have a characteristic flat ribbon-like appearance, and numerous circular spots or pores are to be seen on many of them. The circular markings are more prominent in hard, strong sulfites or sulfates, but are often less distinct in well-boiled pulps. Occasionally the cells are twisted something like cotton fibers. The shape and distribution of the pores in the fibers give some indication of the tree used
Broad-leaf hardwood fibers.	The fibers from broad-leaf trees are shorter and more cylindrical in shape, and are always pointed at each end, and occasionally exhibit cross-markings. In addition to the true fibers, there are always a number of vessels, tubular in shape, short and of very large diameter, which show numerous pits; these establish the presence of fibers from broad-leaf trees

## DIMENSIONS OF FIBER ELEMENTS

Name	Length, mm			Breadth, microns			Source
	Min.	Max.	Mean	Min.	Max.	Mean	
<i>Abelmoschus tetraphyllos</i> .....	0.1	1.6		8	29	13	W
<i>Agave americana</i> (pita).....	1.0	2.2		16	21	17	W
	1.5	4	2.5	20	32	24	V
<i>Aloë perfoliata</i> .....	1.3	3.7		15	24		W
<i>Asclepias</i> (vegetable silk).....	10	30		20	44		W
<i>Bauhinia racemosa</i> .....	1.5	4.0		8	20		W
<i>Beaumontia</i> (vegetable silk)....	30	45		33	50		W
<i>Boehmeria nivea</i> (China grass)...			22.0	40	80	50	W
<i>Boehmeria tenacissima</i> (ramie)...			8.0	16	12.6		W
<i>Bombax heptaphyllum</i> (cotton wool).....	20	30		19	29		W
<i>Bromelia karatas</i> (silk grass)....	1.4	6.7		27	42		W
	2.5	10	5	20	32	24	V
<i>Bromelia pinguin</i> (wild pineapple).....	0.8	2.5	2	8	16	13	V
<i>Calotropis gigantea</i> (bast).....	0.7	3.0		18	25		W
<i>Calotropis gigantea</i> (vegetable silk).....	20	30		12	42	38	W
<i>Cannabis sativa</i> (hemp).....	0.8	4.1		16	32	20	W
	5	55	20	16	50	22	V
<i>Cocos nucifera</i> (coir fiber).....	0.4	0.9		12	20	16	W
	0.4	1	0.7	12	24	20	V
<i>Corchorus capsularis</i> (jute).....	0.8	4.1		10	21	16	W
	1.5	5	2	20	25	22.5	V
<i>Corchorus olitorius</i> (jute).....	0.8	4.1		16	32	20	W
<i>Cordia latifolia</i> .....	0.1	1.6		14.7	16.8	15	W
<i>Corypha umbraculifera</i> (talipot palm).....	1.5	5	3	16	28	24	V
<i>Crotalaria juncea</i> (sunn hemp)...	0.5	6.9		20	42		W
	4	12	8	25	50	30	V
<i>Elaeis guineensis</i> .....	1.5	3.5	2.5	10	13	11	V
Esparto grass.....	1.5	1.9		9	15		W
	0.5	3.5	1.5	7	18	12	V
<i>Gossypium acuminatum</i> (cotton)...			28.4	20.1	29.9	29.4	W
<i>Gossypium arboreum</i> (cotton)....			25.0	20	37.8	29.9	W
<i>Gossypium barbadense</i> (cotton)...			40.5	19.2	27.9	25.2	W
<i>Gossypium conglomeratum</i> (cotton).....			35.1	17	27.1	25.9	W
<i>Gossypium herbaceum</i> (cotton)...			18.2	11.9	22	18.5	W
See also following table							
<i>Hibiscus cannabinus</i> (gambo hemp).....	2	6	5	14	33	21	V
	4.0	12.0		20	41		W
<i>Holoptelea integrifolia</i> .....	0.9	2.1		9	14	12	W
<i>Humulus lupulus</i> (hop).....	4	19	10	12	26	16	V
<i>Kydia calycina</i> .....	1	2		17	24		W
<i>Lagetta lintearia</i> (lace bark)....	3	6	5	10	20		V
<i>Lasiosyphon speciosus</i> .....	0.4	5.1		8	29		W
Linen.....	4	66	25	15	37	20	V
<i>Linum usitatissimum</i> (flax).....	2.0	4.0		12	25	16	W
<i>Lygaeum spartum</i> .....	1.3	4.5	2.5	12	20	15	V



DIMENSIONS OF FIBER ELEMENTS.—(Continued)

Name	Length, mm			Breadth, microns			Source
	Min.	Max.	Mean	Min.	Max.	Mean	
<i>Morinda</i> (vegetable silk).....	10	25		19	33		W
<i>Mauritia flexuosa</i> (ita palm)....	1	3	1.5	10	16	12	V
<i>Melilotus alba</i> (sweet clover)....	5	18	10	20	36	30	V
<i>Musa paradisica</i> (banana).....			5	20	40	28	V
<i>Musa textilis</i> (Manila).....	3	12	6	16	32	24	V
<i>Pandanus odoratissimus</i> .....	1.0	4.2				20	W
Paper mulberry.....		25	10			30	V
<i>Phoenix dactylifera</i> (date palm)...	2	6	3	16	24	20	V
<i>Phormium tenax</i> (New Zealand flax).....	2.5	5.6		8	29	13	W
	5	15	9	10	20	16	V
Pineapple.....	3	9	5	4	8	6	V
<i>Raphia toedigera</i> .....	1.5	3	2.5	12	20	16	V
<i>Salix alba</i> (willow).....		3	2	17	30	22	V
<i>Sansevieria</i> .....	1.5	6	3	15	26	20	V
<i>Sarothamnus vulgaris</i> (broom-grass).....	2	9	5	10	25	15	V
<i>Sida retusa</i> .....	0.8	2.3		15	25		W
<i>Spartium junceum</i> (feather-grass)	5	16	10			20	V
<i>Sponia Wightii</i> .....			4			21	W
<i>Sterculia villosa</i> .....	1.5	3.5		17	25	20	W
<i>Strophanthus</i> (vegetable silk)....	10	56		49	92		W
<i>Thespesia lampas</i> .....	0.9	4.7		12	21	16	W
<i>Tilia europaea</i> (linden-bast).....	1.2	5	2	14	20	16	V
	1.1	2.6				15	W
<i>Tillandsia</i> .....	0.2	0.5		6	15		W
<i>Urena sinuata</i> .....	1.1	3.2		9	24	15	W
<i>Urtica dioica</i> (nettle).....	4	57	27	20	70	50	V
<i>Urtica nivea</i> (ramie) See also	60	250	120		80	50	V
<i>Boehmeria</i> .....							
<i>Yucca</i> .....	0.5	6	4	10	20	15	V

V = Vétillard, *Études sur les fibres végétales textiles*. W = Wiesner, *Die Rohstoffe des Pflanzenreiches*.

## COTTON

DIMENSIONS OF COTTON FIBERS

	Length, mm			Diameter, microns
	Max.	Min.	Av.	
African.....	30.2	22.1	26.2	20.8
Algerian.....			37.5	
Brazilian				
Ceara.....	30.2	22.1	26.2	20.1
Maceo.....			29.3	
Maranhã.....	30.2	23.9	26.9	20.1
Paraíba.....			29.7	
Pernambuco.....	34.8	28.4	31.8	20.1
Surinam.....			30.2	
American				
Georgia.....			25.4	10.3
Louisiana.....			25.0	
Mississippi.....			24.2	13.4
Mobile.....	25.4	19.1	22.1	19.4
Orleans.....	28.4	23.9	26.2	19.2
Tennessee.....			25.1	15.0
Texas.....	28.4	22.1	25.4	19.4
Upland.....	26.9	20.6	23.9	19.4
Chinese.....			21.4	24.1
Egyptian				
Brown.....	38.1	28.4	33.3	18.7
Gallini.....	42.4	31.7	36.3	17.1
Smyrna.....	28.4	22.1	25.4	22.8
White.....	34.8	28.4	31.7	19.5
Indian				
Bengal.....	25.4	19.1	22.1	22.1
Broach.....	25.4	17.5	21.3	21.1
Comptah.....	25.4	19.1	22.1	21.5
Dharwar.....	22.6	17.5	22.1	21.1
Dhollerah.....	26.9	21.3	22.6	21.5
Hingunghat.....	30.2	22.1	26.2	21.1

DIMENSIONS OF COTTON FIBERS.—(Continued)

	Length, mm			Diameter, microns
	Max.	Min.	Av.	
Madras.....	25.4	19.1	22.1	21.1
Oomrawutte.....	26.9	19.1	21.9	21.5
Scinde.....	22.1	12.7	16.5	21.3
Tinnevely.....	26.9	17.5	22.1	21.1
Peruvian				
Rough.....	36.6	23.5	32.5	19.8
Smooth.....	36.6	23.5	32.5	19.5
Sea Island				
Edisto.....			41.9	9.65
Fiji.....	53.8	42.4	46.6	16.2
Fitschi.....			48.7	16.7
Florida.....	45.9	38.1	41.9	16.2
John Isle.....			39.3	
Peruvian.....	44.5	34.8	39.6	17.1
Tahiti.....	44.5	31.7	38.1	16.3
Wodomalam.....			39.0	
West Indian.....	34.8	26.9	31.0	22.8

Physical Properties of Individual Cotton Fibers

Variety	Length, cm	Rigidity, dynes cm <sup>2</sup>	Weight, 10 <sup>-6</sup> g
Sea-island.....	4.2-5	0.010-0.021	5.9-6.7
Egyptian nubarri.....	3.6	0.024	6.3
Egyptian affi.....	3.1	0.032	5.6
Peruvian hybrid.....	2.9	0.063	7.7
Trinidad native.....	2.6	0.045	4.9
Upland Memphis.....	2.6	0.039	5.3
American FGM.....	2.4	0.061	5.6
Upland cross.....	2.3	0.045	5.0
Pernams.....	2.2	0.071	6.7
Indian Bharat.....	1.7	0.111	5.8

The rigidity of the fiber is the torque, or twisting force, in the fiber when 1 cm is given one complete twist.

Pierce<sup>1</sup> furnishes the following physical factors for the cotton fiber, that may be calculated approximately from the staple length:

Staple length.....	$L$ (in cm)
Fiber mass.....	$5.8 \times 10^{-6} \text{ g}$
Mass per centimeter.....	$(5.8/L) \times 10^{-6} \text{ g}$
Wall cross section.....	$(3.9/L) \times 10^{-6} \text{ cm}^2$
Rigidity.....	$0.3/L^2 \text{ dynes cm}^2$
Breaking load.....	$20/L \text{ g}$
Fibers in yarn section.....	$1000L/N \text{ or } (L''/4N) \times 10^4$
Initial couple in yarn.....	$300t/LN = 300p/L\sqrt{N}$

The density of the cotton fiber is assumed as 1.51;  $N$  is the count of the yarn,  $L''$  is the staple length in inches,  $t$  is the twist, and  $p$  the spinning factor  $t/\sqrt{N}$ .

BREAKING STRENGTHS OF DIFFERENT VARIETIES OF COTTON

Cotton	Mean breaking strain	
	Grains	Grams
Sea-island (Edisto).....	83.9	5.45
Queensland.....	147.6	9.59
Egyptian.....	127.2	7.26
Maranhã.....	107.1	6.96
Bengal.....	100.6	6.53
Pernambuco.....	140.2	9.11
New Orleans.....	147.7	9.61
Upland.....	104.5	6.79
Surat (Dhollerah).....	141.9	9.22
Surat (Comptah).....	163.7	10.64

<sup>1</sup> 415, 14: 7; 23.

ABSORPTION OF SODIUM HYDROXIDE BY COTTON<sup>1</sup>

Concn. NaOH, g per 100 cc H <sub>2</sub> O...	0.4	2.0	6.0	8.0	12	16	20	24	28	33	35	40
g NaOH fixed per 100 g cotton....	0.40	0.92	7.4	4.8	4.4	12.6	13	13	15.4	20.4	22.5	22.5

<sup>1</sup> Vieweg, 25, 40: 3876; 07.

## Effect of Mercerizing on the Physical Properties of Cotton Yarns

Thoms<sup>1</sup> obtained the following results on the effect of mercerizing and bleaching on cotton yarns:

	Gray	Boiled	Mer- cerized	Mer- cerized and bleached, chloride of lime
Loss in weight, %.....	0	5.53	4.61	3.02
Loss in length, %.....	0	1.95	1.00	0.37
Mean count.....	16.46	17.66	17.42	17.35
Lea break, in lb.....	97.0	72.41	82.19	86.41
Double thread break, in oz...	27.68	23.26	26.12	27.55
Double thread stretch, in $\frac{1}{16}$ in.....	20.57	14.22	11.08	10.25
Mean turns per in.....	20.18	19.88	19.57	19.99
Moisture, % as regain.....	5.86	5.07	7.18	7.34

	Mercer- ized and bleached, sodium hypo- chlorite	Mercer- ized and bleached, electro- lytic bleach	Bleached, chloride of lime	Bleached, sodium hypo- chlorite
Loss in weight, %...	3.03	3.06	5.00	4.91
Loss in length, %...	1.11	1.14	2.04	1.73
Mean count.....	17.02	17.02	17.35	17.45
Lea break, in lb....	87.12	85.94	17.66	79.97
Double thread break, in oz.....	28.08	27.58	24.14	23.93
Double thread stretch, in $\frac{1}{16}$ in...	11.09	10.78	13.76	13.97
Mean turns per in..	20.20	20.25	20.07	20.11
Moisture, % as re- gain.....	7.55	7.59	5.28	5.46

	Bleached, electro- lytic bleach	Bleached, chloride of lime and mercer- ized	Bleached, sodium hypo- chlorite and mer- cerized	Bleached, electrolytic bleach and mercer- ized
Loss in weight, %	4.88	3.40	3.37	3.37
Loss in length, %	1.97	0.17	0.63	0.10 gain
Mean count.....	17.40	17.58	17.24	17.40
Lea break, in lb..	79.78	80.28	80.47	78.28
Double thread break, in oz....	23.65	26.52	26.14	25.85
Double thread stretch, in $\frac{1}{16}$ in.	13.78	9.08	9.23	8.90
Mean turns per in.	19.89	19.91	19.32	19.59
Moisture, % as regain.....	5.42	7.63	7.69	8.19

<sup>1</sup> 290, 27: 178; 11.

## SILK

SIZES OF COCOON THREADS FROM DIFFERENT SOURCES<sup>1</sup>

Source	Size in deniers
Yellow Piedmont.....	3.06
Yellow Cevennes.....	3.03
White Persians.....	2.87
Yellow Adrianople.....	2.84
Yellow Tuscan.....	2.81
Yellow Salonika.....	2.73
Yellow Greece.....	2.61
Yellow Hungarian.....	2.64
White Turkestan.....	2.68
White Japanese.....	2.12
White Chinese.....	1.96

<sup>1</sup> Report Lyon's Conditioning House.

The single silk filament in the double cocoon thread, therefore, is about  $1\frac{1}{4}$  to  $1\frac{1}{2}$  deniers in size.

COMPARISON OF DIFFERENT VARIETIES OF SILK FIBERS<sup>1</sup>

Name of silk	Country	Diameter, in.		Elasticity, in. in 1 ft.		Tensile strength, dr		Size of cocoon, in.
		Outer fibers	Inner fibers	Outer fibers	Inner fibers	Outer fibers	Inner fibers	
<i>Bombyx mori</i> .....	China	0.00052	0.00071	1.3	1.9	1.6	2.6	1.1×0.5
<i>Bombyx mori</i> .....	Italy	0.00053	0.00068	1.2	1.9	1.9	2.6	1.2×0.6
<i>Bombyx mori</i> .....	Japan	0.00057	0.00069	1.2	1.4	2.0	3.1	1.1×0.6
<i>Bombyx fortunea</i> .....	Bengal	0.00045	0.00051	1.8	2.3	1.6	2.8	1.2×0.5
<i>Bombyx textor</i> ....	India	0.00042	0.00047	1.5	1.9	1.4	2.6	1.2×1.5
<i>Antheraea mylitta</i>	India	0.00161	0.00172	1.9	2.7	6.6	7.8	1.5×0.8
<i>Attacus ricini</i> ....	India	0.00085	0.00093	1.7	2.0	1.5	3.0	1.5×0.8
<i>Attacus Cynthia</i> ..	India	0.00083	0.00097	2.6	2.9	2.4	3.5	1.8×0.8
<i>Antheraea assama</i> ..	India	0.00128	0.00125	2.4	2.9	2.8	4.8	1.8×1.0
<i>Attacus selene</i> ....	India	0.00100	0.00109	2.0	2.8	2.4	4.0	3.0×1.2
<i>Attacus atlas</i> ....	India	0.00102	0.00111	1.9	2.8	2.1	4.1	3.5×0.8
<i>Antheraea yama-</i> <i>mai</i> .....	Japan	0.00088	0.00096	2.0	4.0	6.8	7.5	1.5×0.8
<i>Cricula trifen-</i> <i>estrata</i> .....	India		0.00120					2.0×0.8
<i>Antheraea pernyi</i> ..	China	0.00118	0.00138	2.0	2.7	3.2	5.8	1.6×0.8

<sup>1</sup> Murphy, Textile Industries, p. 6.

## TENSILE STRENGTH

	kg/mm <sup>2</sup>	
	Dry	Wet
Chinese silk.....	53.2	46.7
French raw silk.....	50.4	40.9
French silk, boiled off.....	25.5	13.6
French silk, dyed red and weighted.....	20.0	15.6
French silk, blue-black, weighted 110 %.....	12.1	8.0
French silk, black, weighted 140 %.....	7.9	6.3
French silk, black, weighted 500 %.....	2.2	

## RAYONS OR ARTIFICIAL SILKS

## PHYSICAL PROPERTIES

Type	Breaking strain per denier in g	Elasticity, %
Natural silk.....	2.50	21.6
Chardonnet.....	0.93	8.0
Lehner.....	1.43	7.5
Cuprammonium.....	1.64	12.5
Gelatin.....	0.63	3.8
Viscose.....	1.40	9.5



## BREAKING STRENGTH

Type	kg/mm <sup>2</sup>	
	Dry	Wet
Chardonnet's collodion, undyed.....	14.7	1.7
Lenher's collodion, undyed.....	17.1	4.3
Strehlenert's collodion, undyed.....	15.9	3.6
Cuprammonium, undyed.....	19.1	3.2
Viscose early samples.....	11.4	3.5
Viscose latest samples.....	21.5	
Cotton yarn (for comparison).....	11.5	18.6

Type	Tensile strength per denier in g		Elasticity, %
	Dry	Wet	
Viscose.....	1.3-1.8	0.4-0.8	15
Acetate.....	1.3-1.4	1.5	20
Cuprammonium.....	1.4	0.55	16

## WOOL

EFFECT OF MOISTURE CONTENT ON STRENGTH<sup>1</sup>

Treatment	Average strength of warp strips, lb.	Average elongation before rupture, in.	Moisture content, %
Before treatment.....	160.0	2.26	10.04
After wetting.....	130.7	4.53	53.0
Damp.....	123.6	4.46	33.0
Air-dry.....	156.3	2.67	10.54

<sup>1</sup> Woodmansey, 290, 1918, 227.BREAKING STRENGTH<sup>1</sup>

Kind of wool	Strength in g		
	High	Low	Average
Cotswold.....	44.54	16.10	30.44
Leicester.....	30.00	15.50	23.70
Lincoln.....	36.72	15.79	25.66
Southdown.....	21.29	6.48	12.78
Oxford.....	45.15	19.15	30.43
Merino.....	11.92	3.86	7.35

<sup>1</sup> McMurtie, Reports on the examination of wool fibers.

## ACTION OF CAUSTIC SODA ON BREAKING STRENGTH

NaOH solution, °Bé	Breaking strength, g	NaOH solution, °Bé	Breaking strength, g
Untreated wool	610	32	420
4	510	36	580
8	475	40	770
12	250	42	815
16	180	44	740
20	95	48	720
24	200	50	620
28	240		

ABSORPTION OF VARIOUS ACIDS<sup>1</sup>

% acid used	Hydrochloric acid		Sulfuric acid		Oxalic acid		Acetic acid		Formic acid	
	Absorbed, %	Permanently retained, %	Absorbed, %	Permanently retained, %	Absorbed, %	Permanently retained, %	Absorbed, %	Permanently retained, %	Absorbed, %	Permanently retained, %
1	0.97	0.63	0.97	0.78	0.94	0.72	0.73	0.63	0.33	0.15
2	1.51	0.58	1.90	1.48	1.72	0.95	0.94	0.73	0.71	0.34
3	1.97	0.71	2.67	1.76	2.46	0.94	0.97	0.72	0.95	0.54
4	2.32	0.78	3.58	2.12	3.16	1.33	0.35	1.06	1.35	0.83
5	2.25	0.61	3.48	1.97	3.62	1.51	1.27	0.91	1.51	0.86
6	2.40	0.72	3.86	1.90	4.06	1.31	1.19	0.83	1.78	1.16
7	2.47	0.63	3.72	2.09	4.67	1.53	1.09	0.68	1.58	0.64
8	2.71	0.76	3.80	2.04	5.16	1.78	1.25	0.70	1.55	0.65
9	2.40	0.51	3.62	1.92	5.03	1.53	1.30	0.68	1.71	0.71
10	2.58	0.61	3.79	2.00	5.16	1.39	1.39	0.73	1.48	0.55
11	2.81	0.74	4.17	2.23	5.61	1.71	1.41	0.78	1.81	0.65
12	2.69	0.61	4.06	2.03	5.77	1.47	1.40	0.64	1.54	0.56

<sup>1</sup> Fort and Lloyd, 290, 1914, 5.

## CORDAGE FIBERS

## RELATIVE STRENGTHS

Fiber	Breaking strain of thread in g	Calculated cross section in mm <sup>2</sup>	Breaking strain, g per mm <sup>2</sup>	Breaking strain, tons per in. <sup>2</sup>	Breaking length, km
Sisal.....	1375	0.0240	57 300	36.2	38.2
Sansevieria.....	1289	0.0224	57 540	36.6	38.4
Manila (abaca).....	1655	0.0181	91 430	58.0	60.9
Hedychium.....	828	0.0093	89 300	56.7	59.1
Cotton fiber.....	8.2	0.00026	31 458	20.0	22.8
Cellulose monofil.....	294	0.0140	21 000	13.3	14.0
Strong paper.....					10.0

MINOR HAIR FIBERS<sup>1</sup>

	Mohair	Alpaca	Camel-hair	Cashmere
Length, in.....	9	12	5	3
Strength.....	Very strong	Fairly strong	Fairly strong	Fairly strong
Luster.....	Very high	High	Good	Good
Color.....	White	Vari-colored	Brownish	Brown and white
Fineness, in.....	1/700	1/800	1/800	1/12 000
Handle.....	Fairly soft	Soft	Soft	Very soft
Form of staple....	Straight	Straight	Fairly curly	Fairly curly
Uniformity.....	Uniform	Uniform	Fair	Fair
Uses.....	Dress fabrics, linings, upholstery	Dress fabrics, linings	Dress fabrics	Shawls and hosiery

<sup>1</sup> Barker, Textile Mfr.

The "breaking length" refers to a length of fiber or thread that will break of its own weight.

PHYSICAL PROPERTIES<sup>1</sup>

Fiber	Weight per yd., gr	Breaking strain per strand, g	Breaking length in yd.
Abaca (Manila hemp), <i>Musa textilis</i> :			
Highest.....	0.567	46.6	82.2
Lowest.....	0.962	31.0	32.2
Average.....	0.772	34.8	45.0
Henequen (Yucatan sisal), <i>Agave fourcroya</i> .....	0.765	16.7	21.8
Sisal (Hawaii and East Africa), <i>Agave sisalana</i> .....	0.616	22.7	38.4
Cantala (Manila maguey), <i>Agave cantala</i> .....	0.429	9.6	22.3
Phormium (New Zealand hemp), <i>Phormium tenax</i> .....	0.659	18.8	28.5
Zapupe Vincent ( <i>Agave lespinassei</i> ).....	0.722	21.5	29.7
Cabuya (from Costa Rica), <i>Furcraca cabuya</i> .....	0.574	20.0	32.2

<sup>1</sup> Bureau of Plant Industry, Washington, D. C.

## Comparative Strengths

The following results were from tests made on ropes of the same size and 1.2 m in length<sup>1</sup>:

## COMPARATIVE STRENGTHS, DRY AND WET

Fiber	Dry, kg	Wet, kg
Hemp from Calcutta.....	72	86
Sunn hemp (fresh retted).....	51	72
Sunn hemp (retted after drying).....	27	35
Jute ( <i>Corchorus capsularis</i> ).....	65	66
Jute ( <i>Corchorus olitorius</i> ).....	51	56
Jute ( <i>Corchorus strictus</i> ).....	47	52
Gambo hemp ( <i>Hibiscus cannabinus</i> ).....	52	60
Roselle hemp ( <i>Hibiscus sabdariffa</i> ).....	41	53
<i>Hibiscus abelmoschus</i> .....	49	49
Ramie ( <i>Bahmeria tenacissima</i> ).....	110	126

<sup>1</sup> Royle, *Fibrous Plants of India*.

## COMPARATIVE STRENGTHS OF PREPARED ROPES, AND OF ROPES AFTER STEEPING IN WATER 116 DAYS

Fiber	Prepared ropes			Water-soaked, natural
	Natural	Tanned	Tarred	
Hemp, English.....	47			Rotted
Hemp, Calcutta.....	34	63	20	Rotted
Coir.....	39			24
Sunn hemp.....	31	31	27	Rotted
Jute.....	31	31	28	18
Linen, Calcutta.....	17			Rotted
<i>Agave americana</i> .....	50	36	35	Rotted
<i>Sansevieria zeylanica</i> .....	54	33	22	13

## OKRA, JUTE AND OTHER CORDAGE FIBERS

	Breaking strain, lb.	
	Dry	Wet
Indian okra.....	79	95
Jute.....	113	125
Hemp (Bengal).....	158	190
<i>Hibiscus cannabinus</i> .....	115	133
<i>Hibiscus sabdariffa</i> .....	95	117
<i>Hibiscus strictus</i> .....	104	115
<i>Hibiscus furcatus</i> .....	89	92

FUR FIBERS<sup>1</sup>

## RELATIVE DURABILITY

Species	Durability (otter = 100)
Beaver.....	90
Bear, black or brown.....	94
Chinchilla.....	15
Ermine.....	25
Fox, natural.....	40
Fox, dyed.....	20-25
Goat.....	15
Hare.....	5
Kolinsky.....	25
Leopard.....	75
Lynx.....	25
Marten (skunk).....	70
Mink, natural.....	70
Mink, dyed.....	35
Mole.....	7
Muskrat.....	45
Nutria (Coypu rat), plucked.....	25
Otter, sea.....	100
Otter, inland.....	100
Opossum.....	37
Rabbit.....	5
Raccoon, natural.....	65
Raccoon, dyed.....	50
Sable.....	60
Seal, hair.....	80
Seal, fur.....	80
Squirrel, gray.....	20-25
Wolf.....	50
Wolverene.....	100

<sup>1</sup> Peterson, *The Fur Trade and Fur Bearing Animals*.

## COMPARATIVE BREAKING STRENGTHS

Fiber	Breaking length in km	Breaking strength, kg per mm <sup>2</sup>
Cotton.....	25.0	37.6
Wool.....	8.3	10.9
Raw silk.....	33.0	44.8
Flax fibers.....	24.0	35.2
Jute.....	20.0	28.7
Ramie.....	20.0	28.7
Hemp.....	30.0	45.0
Manila hemp.....	31.8	47.7
Coconut fiber.....	17.8	29.2
Vegetable silk.....	24.5	35.9

	Ramie	Hemp	Flax	Silk	Cotton
Tensile strength.....	100	36	25	13	12
Elasticity.....	100	75	66	400	100
Torsion.....	100	95	80	600	400

## TENSILE STRENGTHS OF FIBERS FOR EQUAL CROSS SECTIONS

Kind of fiber	Relative strength
Human hair.....	100
Lincoln wool.....	96.4
Leicester.....	119.9
Northumberland.....	130.9
Southdown.....	62.3
Australian merino.....	122.8



TENSILE STRENGTHS OF FIBERS FOR EQUAL CROSS SECTIONS.—  
(Continued)

Kind of fiber	Relative strength
Saxony merino.....	224.6
Mohair.....	136.2
Alpaca.....	358.5
Cotton, Egyptian.....	201.8

COMPARATIVE STRENGTHS OF EQUIVALENT YARNS

Kind of yarn	Breaking strain, in oz.	
	1-in. test	27-in. test
Tram silk.....	45.0	40.0
Ramie.....	34.5	24.5
Linen.....	29.5	18.0
American cotton.....	17.0	13.5
Viscose rayon.....	11.0	11.0
Luster worsted.....	9.0	5.0
Botany worsted.....	7.5	3.5

SPECIFIC GRAVITIES

Determined in benzene (Vignon)

Silk, raw.....	1.30 to 1.37
Silk, boiled-off.....	1.25
Wool.....	1.28 to 1.33
Cotton.....	1.50 to 1.55
Mohair.....	1.30
Hemp.....	1.48
Ramie.....	1.51 to 1.52
Linen.....	1.50
Jute.....	1.48

SPECIFIC HEAT

The specific heat of all vegetable textile fibers thus far tested is practically that of cellulose, 0.32;<sup>1</sup> wool, 0.325; silk, 0.33; asbestos, 0.25; glass wool, 0.157.

<sup>1</sup> Limits observed by Dietz, *Leipzig Monatsch. Textilind.*, 1912: 85, 0.319-0.327.

HYGROSCOPIC MOISTURE

VEGETABLE FIBERS<sup>1</sup>

Fiber	Air-dry condition, %	Maximum amount hygroscopic water, %
Cotton.....	6.66	20.99
Flax (Belgian).....	5.70	13.90
Jute.....	6.00	23.30
China-grass.....	6.52	18.15
Manila hemp (abaca).....	12.50	50.00
Sunn hemp.....	5.31	10.87
<i>Hibiscus cannabinus</i> .....	7.38	14.61
<i>Abelmoschus tetraphyllos</i> .....	6.80	13.00
Esparto.....	6.95	13.32
<i>Urena sinuata</i> .....	7.02	15.20
Piassave.....	9.26	16.98
<i>Sida retusa</i> .....	7.49	17.11
<i>Aloë perfoliata</i> .....	6.95	18.03
<i>Bromelia karatas</i> .....	6.82	18.19
<i>Thespesia lampas</i> .....	10.83	18.19
<i>Cordia latifolia</i> .....	8.93	18.22
<i>Bauhinia racemosa</i> .....	7.84	19.12
Tillandsia fiber.....	9.00	20.50
Pita.....	12.30	30.00
<i>Calotropis gigantea</i> (bast).....	5.67	13.13

<sup>1</sup> Wiesner, *Die Rohstoffe des Pflanzenreiches*.

COTTON AND MERCERIZED COTTON<sup>1</sup>

	%
Ordinary cotton, unbleached.....	6.52
Ordinary cotton, bleached.....	6.25
Mercerized without tension, unbleached.....	9.33
Mercerized without tension, bleached.....	9.12
Mercerized with tension, unbleached.....	8.28
Mercerized with tension, bleached.....	8.05

<sup>1</sup> Higgins, 54, 28: 188; 09.

MOISTURE FIXED BY VARIOUS FIBERS AT 100°C IN AN ATMOSPHERE SATURATED WITH STEAM

Fiber, previously dried at 100°C	Water fixed, %
Bleached white cotton.....	23.0
Unbleached linen.....	27.7
Unbleached jute.....	28.4
Bleached silk.....	36.5
Bleached and mordanted wool.....	50.0

(Scheurer, *Bull. Soc. Ind. Mulh.*, 1900: 89.)

MOISTURE ABSORBED BY VARIOUS FIBERS AT 75°F UNDER DIFFERENT CONDITIONS OF HUMIDITY

Relative humidity, %	Moisture, %			Relative humidity, %	Moisture, %		
	Cot-ton	Silk	Wool		Cot-ton	Silk	Wool
5	1.4	1.8	2.2	55	6.3	9.4	13.4
10	2.4	3.2	4.0	60	6.7	9.9	14.2
15	3.0	4.4	5.7	65	7.3	10.5	15.0
20	3.6	5.4	7.1	70	7.9	11.4	16.0
25	3.9	6.1	8.3	75	8.8	12.5	17.1
30	4.3	6.7	9.4	80	9.9	14.0	18.6
35	4.6	7.3	10.4	85	11.4	15.9	20.5
40	5.0	7.8	11.0	90	13.6	18.4	23.2
45	5.3	8.4	11.8	95	17.5	22.7	27.0
50	5.7	8.8	12.6				

See also pp. 316, 323.

EFFECT OF HUMIDITY

EFFECT OF HUMIDITY ON THE TENSILE STRENGTH OF FABRICS OF COTTON, LINEN AND WOOL

Humidity, %	Tensile strength in kg		
	Cotton	Linen	Wool
44	236	272	84.5
44	237	278	82.7
47	244	284	82.2
56	240	296	81.8
56	246	297	79.5
57	248	295	78.6
59	245.5	295	79.0
60	241	295	79.5
62	250	303	79.5
65	251	310	77.0
66	256	312	78.6
68	250.5	300.5	78.6
70	260	319	72.5
71	257.5	324	78.6
72	252	310.5	77.0
72	258	312.5	76.2
75	265	323	76.2
77	264.5	323	75.0
82	268	330	75.8
82	269	330.5	72.7

(Marschik and Breiner, *Leipz. Monatsch. Textilind.*, 1913: 219.)

TENSILE STRENGTHS OF WORSTED YARNS AT DIFFERENT RELATIVE HUMIDITIES

Relative humidity at 70°F, %	Tensile strength, g
45	234
55	231
65	220
75	216
85	191

EFFECT OF MOISTURE ON STRENGTH OF LINEN SAIL CLOTH<sup>1</sup>

Moisture, %	Strength, kg	Moisture, %	Strength, kg
0.0	180	12.0	350
2.2	190	15.0	402
5.5	232	19.1	417
9.0	288	35.0	425

<sup>1</sup> Brun, *Chem. Zeit.*, 1893.EFFECT OF STEAMING ON TENSILE STRENGTH OF WOOLEN CLOTH<sup>1</sup>

Steaming at 100°C, hr	Relative strength		
	Warp	Filling	Mean
Original cloth	100	100	100
3	86	78	82
6	80	75	77
12	75	69	72
24	68	53	60
36	62	37	50
48	40	32	36
60	29	23	26

<sup>1</sup> Scheurer, *Bull. Soc. Ind. Mulh.*, 1893.

EFFECT OF MOISTURE ON COTTON YARN IN FINISHING

Moisture in yarn, %	Breaking strain
2.89 (dry)	39.9
8.93 (usual)	64.0
17.36 (moist)	69.2

## REGAIN

REGAINS IN CONDITIONING VARIOUS FIBERS FIXED BY THE INTERNATIONAL CONGRESS AT TURIN

	%
Silk.....	11
Wool (tops).....	18½
Wool (yarn).....	17
Cotton.....	8½
Linen.....	12
Hemp.....	12
Jute.....	13¾
New Zealand hemp.....	13¾

PERCENTAGE OF MOISTURE IN TEXTILE MATERIALS CORRESPONDING TO PERCENTAGE OF REGAIN

Regain, %	Moisture, %	Regain, %	Moisture, %
5	4.76	12.5	11.11
6	5.66	13	11.50
7	6.54	14	12.28
7.5	6.98	15	13.04
8	7.41	16	13.79
8.5	7.83	17	14.53
9	8.26	18	15.25
10	9.09	19	15.97
11	9.91	20	16.67
12	10.71		

TABLE OF REGAIN FOR COTTON AT VARIOUS TEMPERATURES AND PERCENTAGES OF HUMIDITY

Humidity, %	°F					
	50	60	70	80	90	100
40	5.90	5.79	5.65	5.47	5.25	5.05
50	6.89	6.78	6.63	6.45	6.18	5.86
60	8.00	7.87	7.69	7.44	7.13	6.80
70	9.14	9.00	8.79	8.58	8.32	8.05
80	10.58	10.42	10.23	9.95	9.70	9.60
90	12.28	12.10	11.85	11.56	11.43	11.85
100	14.12	14.00	13.80	13.65	13.70	14.50

REGAIN IN WORSTED TOPS AT 70°F AT DIFFERENT RELATIVE HUMIDITIES OF THE AIR

Relative humidity, %	Regain, %
45	13.33
55	14.51
65	15.37
75	16.38
85	18.92

## HEAT CONDUCTIVITY

HEAT CONDUCTING POWERS OF TEXTILE MATERIALS

	Relative values
Slag wool.....	100
Hair felt.....	117
Cotton felt.....	122
Sheep's wool.....	126
Air space.....	280

Comparative Values of Fibers as Non-Conductors of Heat<sup>1</sup>

A mass of the non-conducting material 1 in. thick was placed on a flat surface of iron kept heated to 310°F; the amount of heat transmitted per hr through the non-conductor was measured in lb. of water heated 10°F, the unit of area being 1 sq. ft. of covering:

Substance	Lb. water heated 10°F	Solid matter in 1 sq. ft., 1 in. thick, parts in 1000	Air occluded, parts in 1000
Loose wool.....	8.1	56	944
Goose feathers.....	9.6	50	950
Carded cotton.....	10.4	20	980
Hair felt.....	10.3	185	815
Fine asbestos.....	49.0	81	919
Air alone.....	48.0	0	1000

<sup>1</sup> Ordway, *Eng. Min. J.*, 1890, 650.

## Heat Retaining Value of Clothing Materials

Count Rumford heated a large thermometer to 70°R and then ascertained the length of time required for the thermometer to fall to 10°R when surrounded with various textile materials, as follows:

	Sec
Air.....	576
Raw silk.....	1284
Sheep's wool.....	118
Cotton.....	1046
Fine lint (linen?).....	1032
Beaver's fur.....	1296
Hare's fur.....	1315
Eiderdown.....	1305

In another series of experiments, however, using the same materials differently arranged, different results were obtained, as follows:



	Sec
Sheep's wool, loosely arranged.....	1118
Woolen thread, wound round bulb.....	934
Cotton, loose.....	1046
Cotton thread, wound round bulb.....	852
Lint, loose.....	1032
Linen thread, wound round bulb.....	873
Linen cloth, wound round bulb.....	786

From these experiments, Rumford showed that the heat-retaining value of clothing depends more on its texture than on its actual material.

### FIREPROOFING

MINIMUM QUANTITY OF CHEMICAL SUBSTANCES REQUIRED TO RENDER 100 PARTS OF COTTON NON-INFLAMMABLE (Duhem)

Reagent	Parts by weight
Tungstate of ammonium.....	12
Sulfate of ammonium.....	4½
Phosphate of sodium.....	30
Chloride of sodium (common salt).....	35
Phosphate of calcium.....	30
Phosphate of magnesium.....	30

### FIREPROOFING.—(Continued)

Reagent	Parts by weight
Chloride of magnesium.....	4-5
Phosphate of zinc.....	20
Sulfate of zinc.....	4½
Borate of aluminum.....	24
Aluminum hydrate.....	3
Chloride of ammonium.....	4¼
Phosphate of ammonium.....	4½
Silicate of sodium.....	50
Borax.....	8½
Chloride of calcium.....	4½
Sulfate of magnesium.....	15
Chloride of potassium.....	45
Borate of zinc.....	20
Phosphate of aluminium.....	30
Boric acid.....	10
Silicic acid.....	30

### LITERATURE

(For a key to the periodicals see end of volume)

For much additional material on textile fibers and a fairly complete bibliography, see Matthews, *The Textile Fibers*, 4th ed., New York, Wiley, 1924.

## TANNINS AND VEGETABLE TANNING MATERIALS

JOHN ARTHUR WILSON

AND

ARTHUR W. THOMAS

The tabulation of the properties of tanning substances of vegetable origin is complicated by the facts that the chemistry of these exceedingly complex substances is still in its infancy, the literature is not always clear, due to confusion in terminology, and the authenticity of the specimen studied is often uncertain. Formulas, especially those reported in the literature before 1910, are of little value, except as they indicate the relative percentages of C, H and O.

### CLASSIFICATION

The earlier classification, based upon color reactions with ferric salts, is of no present value. Two systems are now used: Perkin (34) and Freudenberg (13).

**Perkin's classification:**  $\alpha$ , Gallotannins (Depside);  $\beta$ , Ellagitannins (Diphenylmethyloids);  $\gamma$ , Catechotannins (Phlobatanins). These are characterized by the following reactions:  $FeCl_3$ :  $\alpha$ , blue;  $\gamma$ , green. *Boiling dilute  $H_2SO_4$* :  $\alpha$ , gallic acid is formed;  $\beta$ , ellagic acid ppts.;  $\gamma$ , phlobaphenes or "reds" ppt. *Br*:  $\gamma$  give a ppt. *HCl and pine wood*:  $\gamma$  give phloroglucinol reaction, while  $\alpha$  and  $\beta$  do not.  $C_6H_5N:NCl$ :  $\gamma$  give a ppt., indicating the presence of phloroglucinol or resorcinol groups, while  $\alpha$  and  $\beta$  do not. *Fusion with alkali*:  $\alpha$  yield gallic acid and a little pyrogallol;  $\gamma$  yield protocatechuic acid. *Heating in glycerol*:  $\alpha$  form pyrogallol;  $\gamma$  form catechol. *HCHO and HCl*:  $\gamma$  give complete precipitation, the others do not. *Lead acetate in  $CH_3CO_2H$* :  $\alpha$  are pptd.,  $\gamma$  are not.

**Freudenberg's classification:** **A.** Hydrolyzable tannins in which the benzene nucleus is united to a larger complex through the O atoms. **A1.** Mutual esters of phenolcarboxylic acids or with other hydroxy-acids (Depside). **A2.** Esters of phenolcarboxylic acids with polyatomic alcohols and sugars. **A3.** Glucosides. In this group gallic acid predominates as the phenolic component. There is also the extraordinary distribution of combined caffeic acid and the presence of a new phenolcarboxylic acid in chebulinic

acid. The ellagic acid glucosides also belong here. The most important criterion for the inclusion in this group is the splitting into simple components by hydrolyzing enzymes, especially tannase and emulsin.

**B.** Condensed tannins in which C linkages hold the nuclei together. These are not decomposed into simple components by enzymes. They are generally, not always, precipitated by bromine and under the influence of oxidizing agents or strong acids condense to high molecular weight tannins or "reds." By drastic treatment, preferably by alkalis, the C skeleton is broken up and phloroglucinol, if present, is dissolved out while the remainder of the molecule is transformed mainly into phenolcarboxylic acids. **B1.** Simple ketones such as hydroxybenzophenones and hydroxyphenylstyryl ketones. The phloroglucinol and benzene nuclei are present in equimolecular proportions. **B2.** This group is more complicated. The phloroglucinol and benzene nuclei are present in equimolecular proportions. This class embraces the catechols with their corresponding tannins and "reds." This is the most important class of technically used tannins. **B3.** There is practically nothing that can be said about this class of condensed tannins. It is even impossible to state whether they are really jointly condensed systems. In common with the first class of the condensed tannin group, they are precipitated by bromine and are transformed into "reds." On the other hand, they contain no phloroglucinol nucleus. It is possible that the hydroxycinnamic acids are characteristic components of this class; caffeic acid itself is readily transformed into condensation products of the nature of "reds."

In the following tables, the information is given in the following order: Name; classification (Perkin's being indicated by Greek letters, Freudenberg's by the above combinations of letters and figures); (1), source; (2) color and form in which it is isolated; (3) formula; (4) solvents; (5) specific rotatory power; (6) color with ferric salts; (7) remarks as to constitution, etc.



## I. NATURAL TANNINS

**Beech tannin.**  $\gamma$ . (1) Bark of red beech. (3)  $C_{20}H_{22}O_9$  (34).

**Caffetannic acid.**  $\gamma$ . (1) Coffee berries as Ca and Mg salts; cainia root, *Chiococca brachiata*; *Nux vomica*; St. Ignatius beans; Paraguay tea, *Ilex paraguensis*. (2) Amorphous powder. (4)  $H_2O$ ,  $C_2H_5OH$ . (6) Dark green (34).

**Callutannic acid.**  $\gamma$ . (1) Heather, *Calluna vulgaris*. (2) Amber colored powder. (6) Dark green (34).

**Canaigre tannin.**  $\gamma$ . B3. (1) Tuberous roots of the sorrel, *Rumex hymenosepalus*. (2) Bright yellow powder. (3) C, 58.10; H, 5.33 (34). (4)  $H_2O$ ,  $C_2H_5OH$ . (6) Green (13, 34).

**Catechol.**  $\gamma$ . B2. (6) Green. See Table 3.

**Chebulinic acid, Eutannin.**  $\alpha$ . A2. (1) Myrobalans, fruit of the *Terminalia chebula*. (2) Rhombic prisms, also colorless needles (34). (3) C, 50.60; H, 3.65. Probably  $C_{34}H_{30}O_{23}$  (16). Air-dry substance contains 16.5%  $H_2O$  of crystn., which is lost at 100° (2). Mol. wt. by titration and by boiling point elevation in acetone, 806 (16). (4) Hot  $H_2O$ ,  $C_2H_5OH$ , acetone, ethyl acetate (13). (5)  $\alpha_D$ , +61.7° to 66.9° ( $H_2O$ ) (5).  $\alpha_D^{18}$ , +85°  $\pm$  4° (abs.  $C_2H_5OH$ ) (11);  $\alpha_D^{22}$ , -60 (acetone, 1%) (2).  $\alpha_D$  +59° to 67° ( $C_2H_5OH$ , 1-2%) (13). (6) Blue-black. (7) Apparently union between di-gallolyl-glucose and the dibasic acid,  $C_{14}H_{14}O_{11}$  with elimination of  $2H_2O$  (11, 16). D. at 234° (34).

**Cherry bark tannin.**  $\gamma$ . (1) Bark of *Prunus cerasus*. (3)  $C_{21}H_{20}O_{10} \cdot 0.5H_2O$ . (6) Green (34).

**Chestnut tannin.**  $\alpha$ . A3. (1) Leaves, bark and wood of Spanish chestnut, *Castanea vesca*. (3) Purified tannin, C, 50.79; H, 3.32. Mol. wt. 400 or multiple as detd. by titration (24). (4)  $H_2O$ . (6) Dark green to blue. (7) Tannin from leaves, wood and bark identical. Raw tannin is mixture containing quercetin, sugar, ellagic and gallic acids. Contains no phloroglucinol. Probably similar to tannin of German native oak (24).

**Chinese tannin.** See Gallotannin.

**Chlorogenic acid.** A1. (1) Monopotassium salt combined with one molecule of caffein in coffee beans. (2) Cryst. (3)  $C_{16}H_{18}O_9 \cdot 0.5H_2O$ . (4) Hot  $H_2O$ ,  $C_2H_5OH$ , acetone, ethyl acetate. (5)  $\alpha_D$ , -33.1° ( $H_2O$ , 1-3%). (6) Green ppt. (7) 3, 4-Dihydroxy-cinnamoyl-quinic acid (13).

**Cinchona tannin, quinotannic acid.**  $\gamma$ . B3. (1) Cinchona bark. (2) Light yellow powder. (3)  $C_{14}H_{16}O_9$  (?) (34). (4)  $H_2O$ ,  $C_2H_5OH$  (13). (6) Green ppt. (7) Very hygroscopic.

**Cocatannic acid.**  $\gamma$ . (1) Leaves of *Erythroxylon coca*. (2) Yellow micro. cryst. (3)  $C_{17}H_{22}O_{10} \cdot 2H_2O$  (?) (6) Green (34).

**Colatein.**  $\gamma$ . B2. (1) Cola nuts, *Cola acuminata*. (4) Hot  $H_2O$ ,  $C_2H_5OH$ , acetone. (6) Green. (7) M. P. 257°-288° (13).

**Colatin, Colatannin.**  $\gamma$ . B2. (1) Cola nuts, *Cola acuminata*. (2) Cryst. (13). Light red amorphous powder (34). (3)  $C_{16}H_{20}O_8$  (34). (4)  $C_2H_5OH$ , acetone, ethyl acetate. (5) Inactive. (6) Green. (7) M. P. 148° (13).

**Cortepinitannic acid.**  $\gamma$ . (1) Bark of Scotch fir, *Pinus sylvestris*. (2) Bright red powder. (3)  $C_{32}H_{34}O_{17}$ . (6) Intense green (34).

**Cyanomacclurin.** B2. (1) Wood of *Artocarpus integrifolia*. (2) Cryst. (3)  $C_{15}H_{12}O_6$ . (6) Violet. (7) M. P. above 290° (13).

**m-Digallic acid.**  $\alpha$ . A1. (1) Esterified with glucose in Chinese tannin; also synthetic. See Table 2.

**Ellagic acid.**  $\beta$ . (1) From many tannins containing ellagitannin by boiling with dilute  $H_2SO_4$ . Divi-divi, myrobalans and valonia best sources; also synthetic. See Table 2.

**Filitannin.**  $\gamma$ . B2. (1) Fern-root, *Aspidium filix-mas*. (2) Red-brown powder (34). (3)  $C_{41}H_{36}NO_{18}$  (?) (29, 34). (4)  $C_2H_5OH$ ,  $H_2O$  (29). (5) Inactive (13). (6) Olive-green. (7) Heated at 125°, loses water and becomes insoluble (13).

**Fraxitannic acid.**  $\gamma$ . (1) Leaves of ash tree, *Fraxinus excelsior*. (2) Brownish-yellow deliquescent powder. (3)  $C_{26}H_{32}O_{14}$  (?)

(29, 34). (4)  $H_2O$ ,  $C_2H_5OH$  (29, 34). (6) Dark green ppt. (7) Heated at 100°, loses water and becomes practically insoluble. Yields quinone upon oxidation by permanganate (29, 34).

**Galitannic acid.**  $\gamma$ . (1) Bark of *Galium verum*. (3)  $C_{14}H_{16}O_{10} \cdot H_2O$ . (6) Green (34).

**Gallotannin, Gallotannic acid, Tannin, Tannic acid.**  $\alpha$ . A2. (1) From galls on leaves and buds of various species of oak, especially *Quercus infectoria* and *Q. lusitania* ("Turkish tannin") due to puncture by insects of the genus *Cynips*. From galls on leaves and buds of a species of sumach, *Rhus semialata* ("Chinese tannin") due to puncture of insect, *Aphis chinensis*. (2) Light yellow-brown powder. (3) Average of several specimens, C, 52.59 to 53.70; H, 3.24 to 3.40 (6).  $C_{76}H_{52}O_{46}$  (E. Fischer). Mol. wt., 1247-1636 by boiling point elevation in acetone. (4)  $H_2O$ ,  $C_2H_5OH$ , ethyl acetate. (5)  $\alpha_D^{20}$ , +58° to +70° (different specimens,  $H_2O$ );  $\alpha_D^{20}$ , +18° (one specimen,  $C_2H_5OH$ ) (1, 6);  $\alpha_D^{22}$ , +12.9° (acetone);  $\alpha_D^{22}$ , +17.6° (purified specimen,  $C_2H_5OH$ ) (1, 3). (6) Bluish-black. (7) Hydrolysis of purified specimen by dil.  $H_2SO_4$  yields 93.6% gallic acid and 6.8% glucose (1, 3). Undoubtedly a mixture of at least two individuals (34). The tannin, according to E. Fischer, is penta-m-digallolylglucose. Nierenstein objects, asserting that gallotannin is probably a glucoside of polydigallolyl-leucodigallic acid anhydride or of its free acid (31).

**Gallotannin, Chinese Tannin.**  $\alpha$ . A2. (1) See Gallotannin above. (2) Amorphous yellow to light brown powder. (3) Penta-m-digallolylglucose. Mol. wt., 1700 (13). (4) See Gallotannin above. (5)  $\alpha_D^{26}$ , +73° (purified specimen,  $H_2O$ , 1%) (1, 7);  $\alpha_D$ , +45° to +53° ( $H_2O$ , 20%), rising rapidly on dilution to +135° to +140° ( $H_2O$ , 1.2%) (13);  $\alpha_D$  in formamide, +13°; acetone, +14°;  $C_2H_5OH$ , +18°, glacial acetic acid, +25°; pyridine, +40°. These all showed high and low  $\alpha_D$  fractions in water; were alike in organic solvents. Colloidal forms and impurities markedly affect  $\alpha_D$  in water (23). Two fractions—(a)  $\alpha_D$ , +30° to +40° ( $H_2O$ ); +40° to +41° (pyridine); (b)  $\alpha_D$ , +150° to +158° ( $H_2O$ ); +50° to +51° (pyridine) (27). Purified tannin, after removing part difficultly soluble in water,  $\alpha_D$ , +13.9° ( $C_2H_5OH$ , 3%); +14.9° ( $C_2H_5OH$ , 10%); +13.1° (acetone, 10%) (1, 4). Potassium salt, containing 10.2% K,  $\alpha_D^{18}$ , +46.3° ( $H_2O$ , 1%) (1, 4). (6) Bluish-black. (7) Upon hydrolysis with dil.  $H_2SO_4$  there is produced 88.6% gallic acid and 11.4% glucose (13). This tannin is a mixture of deka-, nona-, and octa-gallolyl-glucoses averaging 8 to 9 gallic acid radicals to 1 molecule glucose. The fractions of lower  $\alpha_D$  contain more depside-like gallic acid (27). See also gallotannin above.

**Gallotannin, Turkish Tannin.**  $\alpha$ . A2. (1) See Gallotannin above. Aleppo galls. (2) Amorphous yellow to light brown powder. (3) C, 52.5; H, 3.5 (13). (4) See Gallotannin above. (5)  $\alpha_D^{17}$ , 2.5° ( $H_2O$ , 7%);  $\alpha_D$ , +5° ( $H_2O$ , 7% and less);  $\alpha_D^{14}$ , +23.2° to +24.2° (acetone, 10%) (1, 8). (6) Bluish-black. (7) Hydrolysis of purified specimens with dil.  $H_2SO_4$ : 81.8 to 84.8% gallic acid; 2.7 to 3.8% ellagic acid; 11.5 to 13.8% glucose; 2.0 to 4.1% tannin residue (1, 8). Hydrolysis and fractionation give a series of fractions of increasing  $\alpha_D$  in alcohol from 15.7° to 43.7°. Concomitantly there is a decrease in ellagic and increase in gallic acid content. The ellagic acid is a part of the tannin molecule. At least 25% of the gallic acid is in depside form, partly directly bound in ester form to the sugar hydroxyl groups (28).

**Gallnut Tannin.**  $\alpha$ . A2. (1) Galls on acorn cups of *Quercus robur* and *Q. pedunculata*. (3) C, 52.0; H, 3.3 (13). (7) Undoubtedly identical with gallotannin.

**Hamamelitannin.**  $\alpha$ . A2. (1) Bark of *Hamamelis virginica*. (2) Fine white needles (13). (3) C, 49.9; H, 4.0;  $H_2O$  of crystn. 17.9%, approximating  $C_{20}H_{20}O_{14} \cdot 6H_2O$  (10, 18). (4) Hot  $H_2O$ ,  $C_2H_5OH$ , acetone, ethyl acetate (13). (5)  $\alpha_D^{23}$ , +29° ( $H_2O$ ,



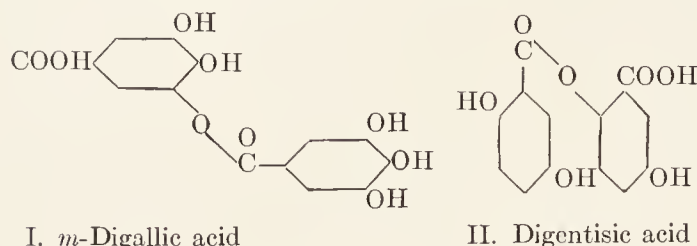
- 2.35 %);  $\alpha_D^{25}$ , +33° (H<sub>2</sub>O, 1.24 %);  $\alpha_D^{30}$ , +35.6° (another specimen, H<sub>2</sub>O, 1.2 %) (10). (7) Contains no free carboxyl group. Acidity, equal to that of pyrogallol, is due to phenolic hydroxyls (10, 18). Upon hydrolysis with dil. H<sub>2</sub>SO<sub>4</sub>: gallic acid, 70 %; sugar, 30 %. Upon hydrolysis with tannase: gallic acid, 66 %; sugar, 34 % (13). M. P., 115°–117° (air-dry); 203° (dried at 100°) (34).
- Hemlock tannin.**  $\gamma$ . (1) Hemlock bark, *Tsuga (Abies) canadensis*. (3) C<sub>20</sub>H<sub>18</sub>O<sub>10</sub> (?). (7) Probably related to quercitannic acid of the oak (29, 34).
- Horsechestnut tannin.**  $\gamma$ . (1) Nearly all parts of the *Aesculus hippocastanum* and in root bark of apple tree. (2) Nearly colorless powder. (3) C<sub>25</sub>H<sub>24</sub>O<sub>12</sub>. (6) Green (34).
- Ipecacuanhic acid.**  $\gamma$ . (1) Roots of *Psychotria ipecacuanha*. (2) Reddish-brown hygroscopic substance. (3) C<sub>14</sub>H<sub>18</sub>O<sub>7</sub>. (6) Green (34).
- Larch tannin.**  $\gamma$ . (1) Bark of the larch, *Larix europea*. (6) Green (34).
- Maclurin.** B1. (1) Wood of "old fustic," *Chlorophora tinctoria*; also synthetic. (2) Yellow crystals (13). Colorless needles when pure (34). (3) C<sub>13</sub>H<sub>10</sub>O<sub>6</sub>. (4) 14°, 1 part in 190 parts H<sub>2</sub>O (13). (6) Green. (7) 2, 4, 6, 3', 4'-Pentahydroxybenzophenone, M. P. 200° (anhydrous form) (34).
- Malletto tannin.**  $\gamma$ . B2. Bark of *Eucalyptus occidentalis* and other species of *Eucalyptus*. (2) Brown powder. (3) (C<sub>19</sub>H<sub>26</sub>O<sub>9</sub>)<sub>n</sub> (29, 34). (4) H<sub>2</sub>O, abs. C<sub>2</sub>H<sub>5</sub>OH (from which it is precipitated by ether) (13). (7) Similar to quebracho tannin (13, 34).
- Mangrove tannin.**  $\gamma$ . B2. (1) *Rhizophora mangle*, *R. mucronata*, *Ceriops candolleana*, *C. roxburghiana*. (2) Amorphous red powder. (3) C<sub>24</sub>H<sub>26</sub>O<sub>12</sub> (29). (6) Green. (7) Closely resembles catechutannic acid (34).
- Mimosa tannin.**  $\gamma$ . (1) Various species of *Mimoseae* such as *Acacia arabica* of Egypt and the "wattles" of Australia. (6) Bluish-violet. (7) With the exception of the reaction with ferric salts, gives all the ordinary reactions of the phlobatannins (34).
- Oak tannin.** B3 (36). (1) Leaves and buds of German oak, *Quercus pedunculata*. (2) Amorphous reddish-yellow powder (22). (3) C, 49.9; H, 4.2. (4) H<sub>2</sub>O, C<sub>2</sub>H<sub>5</sub>OH, acetone (22, 36). (4)  $\alpha_{Hg}$  yellow, -39° ± 10° (H<sub>2</sub>O); -30° ± 4° (CH<sub>3</sub>OH) (21). (7) Tannin from leaves of *Quercus sessiflora* identical (21). Molecule contains 18–25 % bound ellagic acid; 3–7 % bound glucose; and the rest is an amorphous acid, "Quercus acid," C, 50.2; H, 3.6. Titration equivalent about 400 (21, 22).
- Oak tannin, Quercitannic acid.**  $\gamma$ . B2. (1) Bark of various species of *Quercus* (34); Bark of *Quercus robur* (13). (2) Reddish-white powder (34). Light brown powder (13). (3) C<sub>20</sub>H<sub>20</sub>O<sub>4</sub> (?): C, 59.79; H, 5.0 (34). C, 56.8; H, 4.4. C, 55.4; H, 4.1 (13). (6) Green (34). Black-blue (13).
- Oak tannin, Quercin, Quercic acid, Quercinic acid.**  $\gamma$ . B2. (1) Wood of various species of *Quercus*. (2) Light brownish-yellow (34). (3) C<sub>15</sub>H<sub>12</sub>O<sub>9</sub>.2H<sub>2</sub>O (29, 34). C, 48.3; H, 4.5 (13). (6) Blue.
- Paullinia tannin, Guarana tannin.**  $\gamma$ . B2. (1) "Guarana paste" from seeds of *Paullinia cupana*. (2) Small colorless crystals (34). Gray needles (30). (3) C<sub>37</sub>H<sub>35</sub>O<sub>18</sub>.COOH.2H<sub>2</sub>O (30). (4) H<sub>2</sub>O, C<sub>2</sub>H<sub>5</sub>OH, ethyl acetate, glacial acetic acid (30). (5)  $\alpha_D^{20}$ , -74.4° (H<sub>2</sub>O, 10 %);  $\alpha_D^{18}$ , -39.1° (C<sub>2</sub>H<sub>5</sub>OH, 8 %); -48.1° (acetone, 6 %);  $\alpha_D^{20}$ , -56.8° (initial rotation in pyridine, 8 %). By mutarotation falls to constant value of -8.6° (30). (7) M. P. 199°–201° with evolution of CO<sub>2</sub>. Loses two mol. H<sub>2</sub>O of crystn. at 130°. M. P. of anhydrous form 259°–261° with evolution of CO<sub>2</sub> (30). Paullinia catechol isolated from paullinia tannin is identical with "acacatechin" in crystal form and chemical properties. Chemically it is identical with gambier-catechin (13).
- Pinicortannic acid.**  $\gamma$ . (1) Bark of Scotch fir, *Pinus sylvestris*. (2) Reddish-brown powder. (3) (C<sub>16</sub>H<sub>18</sub>O<sub>11</sub>)<sub>2</sub>.H<sub>2</sub>O. (6) Green (34).
- Pistachio tannin.**  $\gamma$ . B2. (1) Leaves of mastie tree, *Pistachia lentiscus*. (2) Pale brown brittle mass (34). (4) H<sub>2</sub>O, C<sub>2</sub>H<sub>5</sub>OH, ethyl acetate (13). (6) Blue-black. (7) Often sold for sumach (34).
- Pomegranate tannin, Ellagitannin.**  $\beta$ . A3. (1) Root bark of *Punica granatum*. (2) Amorphous greenish-yellow powder. (3) C<sub>20</sub>H<sub>16</sub>O<sub>13</sub> (34). Two fractions: A (sol. in H<sub>2</sub>O), C, 50.9; H, 3.4. B (insol. in H<sub>2</sub>O), C, 52.4; H, 3.4 (13). (4) Fraction A: H<sub>2</sub>O, C<sub>2</sub>H<sub>5</sub>OH, ethyl acetate (13). (6) Blue-black. (7) Glucoside of ellagic acid and hexose (13).
- Quebracho tannin.**  $\gamma$ . B2. (1) Wood of *Quebracho colorado*, *Schinopsis lorentzii* and *Balsanae*. (2) Red powder. (3) C, 62.5; H, 5.4. (4) Hot H<sub>2</sub>O, C<sub>2</sub>H<sub>5</sub>OH, ethyl acetate, acetone (13). (6) Green. (7) Tannin is mixture of products insol. in H<sub>2</sub>O and sparingly sol. in cold H<sub>2</sub>O. A benzoyl derivative, C, 73.0; H, 4.2, showed a mol. wt. in benzene of about 2300.
- Rhatany tannin.**  $\gamma$ . Bark of root of rhatany, *Krameria triandra*. (2) Light yellow powder. (4) H<sub>2</sub>O. (6) Green (34).
- Rheotannic acid, Rhubarb tannin.**  $\gamma$ . B2. (1) Rhubarb. (2) Yellowish-brown powder. (3) C<sub>26</sub>H<sub>26</sub>O<sub>14</sub> (34). (4) H<sub>2</sub>O. (6) Black-green ppt. (7) Contains two glucosides, glucogallin (C<sub>13</sub>H<sub>16</sub>O<sub>10</sub>) and tetrarin (C<sub>32</sub>H<sub>32</sub>O<sub>10</sub>) (34). Catechin also present which is probably identical with gambier-catechin (13).
- Rubitanic acid.**  $\gamma$ . (1) Leaves of *Rubia tinctorum*. (3) C<sub>14</sub>H<sub>22</sub>O<sub>12</sub>.0.5H<sub>2</sub>O. (6) Green (34).
- Sequitannic acid.**  $\gamma$ . (1) Cones of *Sequoia gigantea*. (2) Reddish-brown powder. (3) C<sub>21</sub>H<sub>20</sub>O<sub>10</sub> (29, 34). (4) H<sub>2</sub>O, C<sub>2</sub>H<sub>5</sub>OH. (6) Brown-black ppt.
- Spruce bark tannin.**  $\gamma$ . (1) Bark of spruce. (3) C<sub>21</sub>H<sub>20</sub>O<sub>10</sub> (?) (34).
- Sumach tannin.**  $\alpha$ . A2. (1) From leaves of many species of *Rhus*. Also *Coriaria myrtifolia* (French), *Colpoon compressum* (Cape), *Arctostaphylos* (Russian). (2) Yellow powder. (3) C, 52.3; H, 3.5. (*Rhus coriaria*) (13). (4) H<sub>2</sub>O, C<sub>2</sub>H<sub>5</sub>OH, ethyl acetate. (7) Similar to Turkish tannin.
- Tannecortepinic acid.**  $\gamma$ . (1) Bark of young Scotch firs in spring time. (3) C<sub>28</sub>H<sub>26</sub>O<sub>12</sub>. (6) Green (34).
- Tannic acid.** See Gallotannin.
- Tea tannin.**  $\gamma$ . A2. (1) Leaves of black tea. (4) H<sub>2</sub>O, ethyl acetate. (5)  $\alpha_D$ , -177.3° (29). (7) Probably identical with quercitannic acid (29, 34). A gallotannin (13).
- Tormentilla tannin.**  $\gamma$ . (1) Root of *Potentilla tormentilla*. (2) Amorphous reddish powder. (3) C<sub>26</sub>H<sub>22</sub>O<sub>11</sub>. (6) Blue-green (34).
- Turkish tannin.** See Gallotannin.
- Willow bark tannin.**  $\gamma$ . (1) Bark of *Salix triandra*. (6) Green. (7) Glucoside tannin (34).

## II. SYNTHESIZED TANNINS

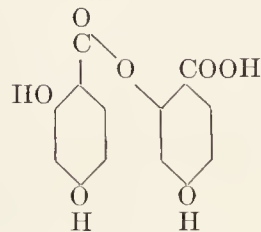
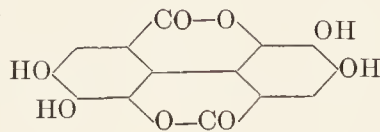
- m-Digallic acid.**  $\alpha$ . A1. (2) Fine needles. (3) I (13). (4) CH<sub>3</sub>OH, C<sub>2</sub>H<sub>5</sub>OH, C<sub>6</sub>H<sub>11</sub>OH. 23°, 1 part in 950 parts H<sub>2</sub>O; 1 part in 350 parts ethyl acetate; 1 part in 2000 parts ether (1, 5). 25°, 1 part in 1900 parts H<sub>2</sub>O. 100°, 1 part in 50–60 parts H<sub>2</sub>O (13). (5) Inactive. (6) Blue-black. (7) Found esterified with glucose in Chinese tannin. When hot aq. solution is chilled, it jellifies (13). M. P., 275° (282° corr.) with foaming and decomposition (1, 5).
- Digalloyl-levoglucosan.** A2. (2) Micro-needles. (3) C<sub>20</sub>H<sub>18</sub>O<sub>13</sub>. (4) H<sub>2</sub>O, C<sub>2</sub>H<sub>5</sub>OH, acetone. (5)  $\alpha_D^{18}$ , -27.9° (C<sub>2</sub>H<sub>5</sub>OH, 1.8 %). (6) FeCl<sub>3</sub> gives blue-black ppt. in C<sub>2</sub>H<sub>5</sub>OH solution. (7) Decomposes 220°, carbonizes 270° (26).
- Digentic acid.**  $\alpha$ . (2) Fine needles. (3) II. (4) 0°, 1 part in 900 parts H<sub>2</sub>O. (5) Inactive. (6) Fugitive blue and ppt. (1, 5). (7) Dry form melts 204°–205° (208°–209° corr.) with sintering.



**Diprotocatechuic acid.**  $\alpha$ . (2) Fine needles. (3)  $(\text{OH})_2\text{C}_6\text{H}_3\text{CO.O.C}_6\text{H}_3(\text{OH})\text{COOH}$ . (4) Acetone,  $\text{CH}_3\text{OH}$ . 1 part in 2500 parts  $\text{H}_2\text{O}$ . (5) Inactive. (6) Blue-green. (7) M. P.  $237^\circ\text{--}239^\circ$  (corr.) (1, 5).

I. *m*-Digallic acid

II. Digentisic acid

III. Di- $\beta$ -resorcylic acid

IV. Ellagic acid

**Di- $\beta$ -resorcylic acid.**  $\alpha$ . (2) Micro-needles. (3) III. Isomeric with digentisic acid. (4)  $\text{C}_2\text{H}_5\text{OH}$ , acetone, ethyl acetate, hot  $\text{H}_2\text{O}$ , ether. (5) Inactive. (6) Violet red. (7) Foams and decomposes at about  $210^\circ$  ( $215^\circ$  corr.) (1, 5).

**Ellagic acid.**  $\beta$ . (2) Cryst. from pyridine in prismatic needles which are converted by  $\text{C}_2\text{H}_5\text{OH}$  to a pale yellow cryst. powder. (3)  $\text{C}_{14}\text{H}_6\text{O}_8 \cdot 2\text{H}_2\text{O}$ . IV. (5) Inactive. (7) Above  $360^\circ$  sublimes with carbonization (34). Not a true tannin. See Table 1.

**Hexagalloyl mannite.** A2. (2) Amorphous brown powder. (3)  $\text{C}_6\text{H}_5\text{O}_6[\text{CO.C}_6\text{H}_2(\text{OH})_3]_6$ . (4)  $\text{H}_2\text{O}$ ,  $\text{C}_2\text{H}_5\text{OH}$ , acetone, ethyl acetate. (5)  $\alpha_D^{18}$ ,  $+27.0^\circ$  ( $\text{C}_2\text{H}_5\text{OH}$ , 2%). (6) Dark blue (1, 4).

**Maclurin.** B1. See Table 1.

**Penta-*m*-digalloyl- $\alpha$ -glucose.** A2. (2) Light brown amorphous mass. (3)  $\text{C}_{76}\text{H}_{52}\text{O}_{46}$ . (4)  $18^\circ$ , 1 part in 200 parts  $\text{H}_2\text{O}$ . (5) Prepared by alkaline hydrolysis of acetates:  $\alpha_D^{18}$ ,  $+36^\circ$  ( $\text{C}_2\text{H}_5\text{OH}$ , 10%);  $+40^\circ$  to  $41^\circ$  (acetone, 10%);  $43.8^\circ$  ( $\text{H}_2\text{O}$ , 1%) (1, 3). Prepared from acetates by  $\text{CH}_3\text{OH}$  and  $\text{HCl}$ :  $\alpha_D^{18}$ ,  $+41.3^\circ$  ( $\text{C}_2\text{H}_5\text{OH}$ , 5%);  $+44.6^\circ$  (acetone, 5%);  $+51^\circ$  ( $\text{H}_2\text{O}$ , 0.5%) (1, 4). (6) Blue-black. (7) Potassium salt containing 10.3% K,  $\alpha_D^{18}$ ,  $+56.6^\circ$  ( $\text{H}_2\text{O}$ , 5%) (1, 4).

**Penta-*m*-digalloyl- $\beta$ -glucose.** A2. (2) Light brown amorphous mass. (3)  $\text{C}_{76}\text{H}_{52}\text{O}_{46}$ . (4)  $20^\circ$ , 1 part in 1000 parts  $\text{H}_2\text{O}$ . (5) Prepared by alkaline hydrolysis of acetates:  $\alpha_D^{18}$ ,  $+14.9^\circ$  ( $\text{C}_2\text{H}_5\text{OH}$ , 10%);  $+13.1^\circ$  (acetone, 10%);  $+42.3^\circ$  ( $\text{H}_2\text{O}$ , 1%) (1, 3). Prepared from acetates by  $\text{CH}_3\text{OH}$  and  $\text{HCl}$ :  $\alpha_D^{18}$ ,  $+10.8^\circ$  ( $\text{C}_2\text{H}_5\text{OH}$ , 5%);  $+10.8^\circ$  (acetone, 5%);  $+21^\circ$  ( $\text{H}_2\text{O}$ , 0.1%) (1, 4). (6) Blue-black. (7) Apparently identical with Chinese tannin. Potassium salt containing 10.3% K,  $\alpha_D^{18}$ ,  $+33.7^\circ$  ( $\text{H}_2\text{O}$ , 0.5%) (1, 4).

**Pentagalloyl- $\alpha$ -glucose.** A2. (2) Yellow mass. (3)  $[(\text{OH})_3\text{C}_6\text{H}_2\text{CO}]_5\text{C}_6\text{H}_7\text{O}_6$ . (4)  $\text{H}_2\text{O}$ ,  $\text{C}_2\text{H}_5\text{OH}$ , ether (1, 3). (5)  $\alpha_D^{18}$ ,  $+66.5^\circ$  ( $\text{H}_2\text{O}$ , 1%).  $\alpha_D^{23}$ ,  $65.4^\circ$  ( $\text{H}_2\text{O}$ , 1%).  $\alpha_D^{20}$ ,  $+77.0^\circ$  ( $\text{C}_2\text{H}_5\text{OH}$ , 3%).  $\alpha_D^{18}$ ,  $76.4^\circ$  ( $\text{C}_2\text{H}_5\text{OH}$ , 2%) (1, 3).  $\alpha_D^{16}$ ,  $+60^\circ$  ( $\text{H}_2\text{O}$ , 1%);  $+81.5^\circ$  ( $\text{C}_2\text{H}_5\text{OH}$ , 2%) (1, 4). (6) Blue-black.

**Pentagalloyl- $\beta$ -glucose.** A2. (2) Yellow mass. (3)  $[(\text{OH})_3\text{C}_6\text{H}_2\text{CO}]_5\text{C}_6\text{H}_7\text{O}_6$ . (4)  $\text{H}_2\text{O}$ ,  $\text{C}_2\text{H}_5\text{OH}$  (1, 3). (5)  $\alpha_D^{18}$ ,  $+13.1^\circ$  ( $\text{H}_2\text{O}$ , 1%);  $+13.6^\circ$  ( $\text{H}_2\text{O}$ , 10%);  $+23.3^\circ$  ( $\text{C}_2\text{H}_5\text{OH}$ , 2%) (1, 3).  $\alpha_D^{18}$ ,  $+15^\circ$  ( $\text{H}_2\text{O}$ , 1%);  $+24^\circ$  ( $\text{C}_2\text{H}_5\text{OH}$ , 2%). (6) Blue-black. (7) Potassium salt contains 10.1% K.

**Pentaprogallol-carboyl-glucose.** A2. (2) Amorphous powder. (3)  $[(\text{OH})_3\text{C}_6\text{H}_2\text{CO}]_5\text{C}_6\text{H}_7\text{O}_6$ . (4) Hot  $\text{H}_2\text{O}$ ,  $\text{C}_2\text{H}_5\text{OH}$ , acetone. (5)  $\alpha_D^{18}$ ,  $+69^\circ$  ( $\text{H}_2\text{O}$ , 2.5%). (6) Dark blue (1, 9). (7) Sinters at  $160^\circ$  and melts at about  $200^\circ$  with decomposition.

**Tetragalloyl-erythrite.** A2. (2) Cryst. (3)  $[(\text{OH})_3\text{C}_6\text{H}_2\text{CO}]_4\text{C}_4\text{H}_6\text{O}_4$ . (4) Hot  $\text{H}_2\text{O}$ ,  $\text{C}_2\text{H}_5\text{OH}$ , acetone, mixtures of  $\text{H}_2\text{O}$  and  $\text{C}_2\text{H}_5\text{OH}$ . (7) Decomposes at about  $308^\circ$  (1, 4).

**Tetragalloyl- $\alpha$ -methylglucoside.** A2. (3)  $\text{C}_{35}\text{H}_{30}\text{O}_{22}$ . (4) Identical with pentagalloyl-glucoses. (5)  $\alpha_D^{20}$ ,  $+26.4^\circ$  ( $\text{H}_2\text{O}$ , 4%). (6) Identical with pentagalloyl-glucoses in reactions. (7) M. P.  $130^\circ\text{--}140^\circ$  with decomposition (1, 6).

**Trigalloyl-acetone-glucose.** A2. (2) Amorphous light brown mass. (3)  $[\text{C}_6\text{H}_2(\text{OH})_3\text{CO}]_3\text{C}_6\text{H}_7\text{O}_6(\text{C}_3\text{H}_6)$ . (4) Warm  $\text{H}_2\text{O}$ ,  $\text{CH}_3\text{OH}$ ,  $\text{C}_2\text{H}_5\text{OH}$ , acetone, ethyl acetate. (5)  $\alpha_D^{20}$ ,  $-93^\circ$  (dry acetone, 4%). (6) Blue-violet (1, 2).

**Trigalloyl-glucose.** A2. (2) Amorphous yellowish brown mass. (3)  $[\text{C}_6\text{H}_2(\text{OH})_3\text{CO}]_3\text{C}_6\text{H}_7\text{O}_6$ . (4) Cold  $\text{H}_2\text{O}$ ,  $\text{CH}_3\text{OH}$ ,  $\text{C}_2\text{H}_5\text{OH}$ , acetone, ethyl acetate, pyridine. (5)  $\alpha_D^{20}$ ,  $-118^\circ$  (dry acetone, 2.5%). (6) Deep violet (1, 2).

**Trigalloyl-glycerol.** A2. (2) Amorphous yellowish brown mass. (3)  $[(\text{OH})_3\text{C}_6\text{H}_2\text{CO}]_3\text{C}_3\text{H}_5\text{O}_3$ . (4)  $\text{H}_2\text{O}$ , acetone, ethyl acetate, warm ether. (6) Deep blue (1, 4).

**$\alpha$ -Trigalloyl-levoglucosan.** A2. (2) Micro. hexagonal crystals. (3)  $\text{C}_{27}\text{H}_{22}\text{O}_{17}$ . (4) Hot acetone. (5)  $\alpha_D^{18}$ ,  $-18.0^\circ$  ( $\text{C}_2\text{H}_5\text{OH}$ , 19%). (6)  $\text{FeCl}_3$  gives blue-black ppt. in  $\text{C}_2\text{H}_5\text{OH}$  solution. (7) Decomposes  $250^\circ\text{--}300^\circ$ , carbonizes  $320^\circ$  (26).

**$\beta$ -Trigalloyl-levoglucosan.** A2. (2) Micro-needles. (3)  $\text{C}_{27}\text{H}_{22}\text{O}_{17}$ . (5)  $\alpha_D^{18}$ ,  $-21.0^\circ$  ( $\text{C}_2\text{H}_5\text{OH}$ , 1%). (6)  $\text{FeCl}_3$  gives blue-violet ppt. in  $\text{C}_2\text{H}_5\text{OH}$  solution. (7) Decomposes  $270^\circ$ , carbonizes  $320^\circ$  (26).

### III. CATECHOLS OR CATECHINS

***d*-Catechol.** (1) Acacia and gambier catechus. (2) Thin needles. (3)  $\text{C}_{15}\text{H}_{14}\text{O}_6 \cdot 4\text{H}_2\text{O}$  (20). (4)  $\text{C}_2\text{H}_5\text{OH}$ , ethyl acetate, pure ether. Anhydrous form almost insoluble in latter two. (5)  $\alpha_{578}$ ,  $+17^\circ$  (50% acetone, 9%) (14, 15, 19, 20).  $\alpha_{578}$ ,  $\pm 0^\circ$  ( $\text{C}_2\text{H}_5\text{OH}$ ) (20).  $\alpha_D$ ,  $-2^\circ$  ( $\text{C}_2\text{H}_5\text{OH}$ ) (20).  $\alpha_D^{18}$ ,  $-0.47^\circ \pm 0.03^\circ$  ( $\text{C}_2\text{H}_5\text{OH}$ , 9%);  $+3.7^\circ \pm 0.5^\circ$  (50%  $\text{C}_2\text{H}_5\text{OH}$ , 9%).  $\alpha_D^{20}$ ,  $+18.4^\circ \pm 0.9^\circ$  ( $\text{H}_2\text{O}$ , 0.9%, increasing markedly with temperature decrease) (14). (7) For discussion of structural formula see (20, 29, 33). M. P.  $93^\circ\text{--}95^\circ$ ; anhyd.,  $174\text{--}5^\circ$ .

***l*-Catechol.** (1) Isolated from acacia and gambier catechus. (2) Thin needles. (3)  $\text{C}_{15}\text{H}_{14}\text{O}_6 \cdot 4\text{H}_2\text{O}$ . (5)  $\alpha_{578}$ ,  $\pm 0^\circ$  ( $\text{C}_2\text{H}_5\text{OH}$ );  $\alpha_{578}$ ,  $-16.8^\circ$  (50% acetone, 3%) (20). (7) M. P.  $93^\circ\text{--}95^\circ$ ; anhyd.,  $174^\circ\text{--}175^\circ$  (19, 20).

***dl*-Catechol.** (1) Principal constituent of catechol separated from acacia catechu. (2) Thin needles. (3)  $\text{C}_{15}\text{H}_{14}\text{O}_6 \cdot 3\text{H}_2\text{O}$ . (7) Is "acacatechin" (19). Sinters at  $100^\circ$ , melts  $214^\circ\text{--}216^\circ$  with decomposition (19, 20).

**Catechol-a.** (1) Acacia catechu (33, 35). (3)  $\text{C}_{15}\text{H}_{14}\text{O}_6 \cdot 3\text{H}_2\text{O}$  (35). (7) Is *dl*-catechol (14). Methylated "acacatechin" has same melting point and crystal form as synthetic methyl compound (14). M. P.  $204^\circ\text{--}205^\circ$  (35).

**Catechol-b, Gambier catechol.** (1) Gambier catechu (33, 35). (7) Identical with *d*-catechol in crystal form, melting point, solubility, and constitution.

**Catechol-c.** (1) Gambier catechu. (2) Small pale yellow prisms (35). (3)  $\text{C}_{15}\text{H}_{14}\text{O}_6$ . (7) Identified as *d*-epicatechol (20). M. P.  $235^\circ\text{--}237^\circ$  (35).

**Chinese rhubarb catechol.** (5)  $\alpha_{578}$ ,  $+18^\circ$  (50% acetone) (15).

**Mahogany catechol.** (5)  $\alpha_D$ ,  $+23^\circ$  (50% acetone).  $\alpha_{578}$ ,  $+16^\circ$  (50% acetone);  $+15^\circ$  ( $\text{C}_2\text{H}_5\text{OH}$ ) (15).

**Paullinia catechol.** (5) Inactive in  $\text{C}_2\text{H}_5\text{OH}$ .  $\alpha_D$ ,  $+3.7^\circ$  (50% acetone) (15).

***d*-Epicatechol.** (2) Thick prisms. (3)  $\text{C}_{15}\text{H}_{14}\text{O}_6 \cdot 4\text{H}_2\text{O}$ . (5)  $\alpha_{578}$ ,  $+68.9^\circ$  ( $\text{C}_2\text{H}_5\text{OH}$ , 7%);  $+59.9^\circ$  (50% acetone, 4%). (7) M. P.  $245^\circ$  (20).

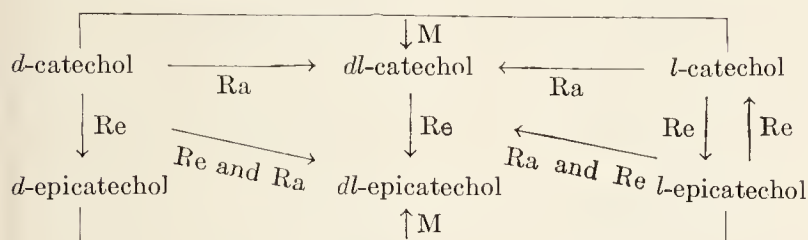
***l*-Epicatechol.** (1) Gambier and acacia catechus (19). (2) Thick prisms. (3)  $\text{C}_{15}\text{H}_{14}\text{O}_6 \cdot 4\text{H}_2\text{O}$  (19, 20). (5)  $\alpha_{578}$ ,  $-68.2^\circ$  ( $\text{C}_2\text{H}_5\text{OH}$ , 6%);  $-59.0^\circ$  (50% acetone, 4%) (19, 20). (7) M. P.  $245^\circ$ .



- dl*-Epicatechol. (1) Gambier and acacia catechus (19). (2) Exists both as prisms and needles. (3)  $C_{15}H_{14}O_6 \cdot 4H_2O$ . (7) M. P. of prisms, 224°–226° (20).
- d*- $\beta$ -Gambier catechol-carboxylic acid. (2) Micro-needles. (3)  $C_{16}H_{14}O_8$ . (5)  $\alpha_D^{20}$ , +12.6° ( $H_2O$ , 5%); +17.6° ( $C_2H_5OH$ , 7%). (7) M. P. 249°–251° with evolution of  $CO_2$  (30).
- l*- $\beta$ -Gambier catechol-carboxylic acid. (2) Large needles. (3)  $C_{16}H_{14}O_8$ . (5)  $\alpha_D^{18}$ , –22.4° ( $H_2O$ , 5%).  $\alpha_D^{17}$ , –31.6° ( $C_2H_5OH$ , 6%). (7) M. P. 258°–261° with evolution of  $CO_2$  (30).
- dl*- $\beta$ -Gambier catechol-carboxylic acid. (3)  $C_{16}H_{14}O_8$ . (7) M. P. 252°–253° with evolution of  $CO_2$  (30).

The relationship between the catechols and epicatechols is shown as follows:

M = mixing; Ra = racemizing; Re = rearrangement (20).



## LITERATURE

(For a key to the periodicals see end of volume)

- (1) Fischer, *Untersuchungen über Depside und Gerbstoffe*, 1919. (2) Fischer and Bergmann, 25, 51: 298; 18. (3) *Idem.*, 25, 51: 1760; 18. (4) *Idem.*, 25, 52: 829; 19. (5) Fischer and Freudenberg, 8, 384: 225; 11. (6) *Idem.*, 25, 45: 915; 12. (7) *Idem.*, 25, 45: 2709; 12. (8) *Idem.*, 25, 47: 2485; 14. (9) Fischer and Rapaport, 25, 46: 2389; 13.
- (10) Freudenberg, 25, 52B: 177; 19. (11) *Idem.*, 25, 52B: 1238; 19. (12) *Idem.*, 25, 53B: 1416; 20. (13) *Idem.*, *Die Chemie der natürlichen Gerbstoffe*, 1920. (14) Freudenberg, Böhme and Beckendorf, 25, 54B: 1204; 21. (15) Freudenberg, Böhme and Purrmann, 25, 55B: 1734; 22. (16) Freudenberg and Fick, 25, 53B: 1728; 20. (17) Freudenberg, Orthner and Fekentscher, 8, 436: 286; 24. (18) Freudenberg and Peters, 25, 53B: 953; 20. (19) Freudenberg and Purrmann, 25, 56B: 1185; 23.
- (20) Freudenberg and Purrmann, 8, 437: 274; 24. (21) Freudenberg and Vollbrecht, 8, 429: 284; 22. (22) *Idem.*, 25, 55B: 2420; 22. (23) Freudenberg and Scilasi, 25, 55B: 2813; 22. (24) Freudenberg and Walpuski, 25, 54B: 1695; 21. (25) Iljin, 52, 82: 422; 10. (26) Karrer and Salomon, 37, 5: 108; 22. (27) Karrer, Salomon and Peyer, 37, 6: 3; 23. (28) Karrer, Widmer and Staub, 8, 433: 288; 23. (29) Nierenstein, *Abderhalden's Biochemisches Handlexikon*, vol. 7, 1912.
- (30) Nierenstein, 4, 121: 23; 22. (31) *Idem.*, 54, 41: 29; 22. (32) *Idem.*, 1, 46: 2793; 24. (33) Perkin, 4, 87: 398; 05. (34) Perkin and Everest, *The Natural Organic Coloring Matters*, 1918. (35) Perkin and Yoshitake, 4, 81: 1160; 02. (36) Vollbrecht, 259, 1921: 1.

## SOURCE AND TANNIN CONTENT OF VEGETABLE TANNING MATERIALS

The names and tannin contents listed were taken from the literature at large for what they may be worth; in some cases the information given may be considerably in error. The place grown may indicate either the place where the sample analyzed was grown or the place where the material grows in abundance. In

the majority of cases, at least, the tannin contents are supposedly those of the air-dried material.

In using the tannin figures, it should be recognized that they are not true tannin contents, but merely figures obtained by methods open to very serious question. A number of slightly different methods were used, but all conformed roughly to the following general scheme. A solution of the tanning material of concentration confined to certain limits was treated with lightly chrome-tanned hide powder until no tannin was left in solution; i.e., the solution no longer gave a precipitate with gelatin solution. The decrease in concentration of all matters in solution was then taken as the measure of the tannin content. Obviously all substances of a slightly acid nature would be removed to some extent by the hide powder and hence all figures must be high where these are present.

The probable magnitude of the error was shown by Wilson and Kern for a number of the commoner tanning extracts. By first freeing the tannin solution of tannin by shaking with hide powder and then freeing the hide powder from nontannin by washing, they were able to estimate the tannin by the increase in weight of the dried hide powder. The tannin contents so obtained differed in many cases by startling amounts from those obtained by the methods generally accepted as official.

The comparison is with the official method of the American Leather Chemists' Association, which is similar in principle to the methods employed in other countries.<sup>1</sup>

Tanning material	Per cent tannin found	
	A. L. C. A. method	Wilson-Kern method
Chestnut wood extract.....	25.80	11.90
Gambier extract.....	24.95	7.79
Hemlock bark.....	10.06	6.17
Hemlock bark extract.....	26.68	23.38
Oak bark extract.....	24.20	12.88
Osage orange extract.....	39.87	13.37
Quebracho extract.....	68.01	47.41
Spruce bark extract.....	22.14	11.71
Sumac extract.....	25.51	16.29
Sumac leaves.....	25.56	9.61
Wattle bark extract.....	33.55	24.16

Many of the tanning materials are leached on a large scale by extract manufacturers and the concentrated extracts are available on the market showing a tannin content by the A. L. C. A. and similar methods of from 20 to 35% for liquid extracts and from 45 to 70% for solid extracts.

It may be assumed that nearly every form of plant life contains some tannin. The following list is not complete but is intended to serve as a guide to those whose interests might be directed into these fields of work.

<sup>1</sup> For a detailed comparison of the methods and their interpretation, see J. A. Wilson, *The Chemistry of Leather Manufacture*, p. 215–31 (The Chemical Catalog Co., New York, 1923).

## SOURCE AND TANNIN CONTENT OF VEGETABLE TANNING MATERIALS

Botanical name	Common name	Place grown	Per cent tannin
<i>Abies alba</i> .....	White spruce	Northern America	Bark 7-13
<i>Abies canadensis</i> .....	Hemlock fir	Northern America	Bark 8-15
<i>Abies dumosa</i> .....	Hemlock spruce	Northern America	Bark 10
<i>Abies excelsa</i> .....	Norway spruce	Northern Europe	Bark 7-13
<i>Abies grandis</i> .....	Lowland fir	California	Bark 9
<i>Abies pectinata</i> .....	Silver fir	Europe	Bark 6-15
<i>Acacia acuminata</i> .....	Raspberry jam wood	Australia	Bark 7-15
<i>Acacia angica</i> .....	Angiea	Brazil	Bark 20-25
<i>Acacia anema</i> .....	Mulga	New South Wales	Bark 5-9
<i>Acacia arabica</i> .....	Babul	India	{ Bark 12-20 Pods 20-42
<i>Acacia binervata</i> .....	Black wattle	Australia	Bark 30
<i>Acacia catechu</i> .....	Cuteh	India	Wood ext. 60
<i>Acacia cavenia</i> .....	Espinillo	South America	{ Pods 18-21 Bark 6
<i>Acacia cebil</i> .....	Red eebil	Argentina	{ Bark 10-15 Leaves 6-7
<i>Acacia cunninghamii</i> .....		Queensland	Bark 9
<i>Acacia curupi</i> .....	Curupy	South America	Bark 18
<i>Acacia dealbata</i> .....	Wattle	Africa and Asia	Bark 17-23
<i>Acacia decurrens</i> .....	Wattle	Australia	Bark 18-51
<i>Acacia granulosa</i> .....		New Caledonia	Bark 12
<i>Acacia homalophylla</i> .....	Yarran	New South Wales	Bark 9
<i>Acacia horrida</i> .....	Doornboseh	Cape Good Hope	Bark 8-18
<i>Acacia koa</i> .....	Koa tree	Hawaii	Bark 18
<i>Acacia leptocarpa</i> .....		Queensland	Bark 10
<i>Acacia longifolia</i> .....		Cyprus	Bark 15
<i>Acacia melanoxylon</i> .....	Blackwood	New South Wales	{ Bark 11 Leaves 3
<i>Acacia microbotrya</i> .....	Manna wattle	Australia	{ Bark 18-27 Leaves and twigs 20
<i>Acacia mollissima</i> .....	Green wattle	Australia	Bark 12-47
<i>Acacia nerifolia</i> .....		Australia	Bark 14
<i>Acacia oswaldi</i> .....	Miljie	Australia	Bark 10
<i>Acacia penninervis</i> .....	Hiekory	Europe	Bark 14-38
<i>Acacia podalyriaefolia</i> .....		Queensland	Bark 12
<i>Acacia polystachya</i> .....		Queensland	Bark 18
<i>Acacia pycnantha</i> .....	Golden wattle	Australia	Bark 40-50
<i>Acacia salicina</i> .....		Australia	Bark 6-8
<i>Acacia sentis</i> .....		New South Wales	Bark 6
<i>Acacia seyal</i> .....	Talh	Sudan	Bark 18
<i>Acacia sp.</i> .....	Gallol	Somaliland	Bark 24
<i>Acacia spiralis</i> .....	Guaie	New Caledonia	Bark 17
<i>Acer campbellii</i> .....	Himalayan maple	India	Bark 3
<i>Acer campestre</i> .....	Field maple	Europe	Bark 4
<i>Alchornea triplinervia</i> .....	Tapia gwazu-ih	Paraguay	Bark 12
<i>Allophylus edulis</i> .....	Koku	Paraguay	Bark 10
<i>Alnus firma</i> .....	Minibari	Japan	Fruits 25
<i>Alnus glutinosa</i> .....	Alder	Europe	Bark 16-20
<i>Alnus incana</i> .....	Grey alder	Europe	Bark 10
<i>Alnus maritima</i> .....	Hannoki	Japan	Fruits 25
<i>Alnus oregona</i> .....	Red alder	Pacific states	Bark 9
<i>Anacardium occidentale</i> .....	Kashew nut	India	Bark 9
<i>Anogeissus acuminata</i> .....	Yon	India	Bark 10
<i>Anogeissus latifolia</i> .....	Dhawa	India	{ Bark 16 Leaves 10-18 Shoots 20-30 Red tips 54
<i>Anogeissus pendula</i> .....		India	Bark 9
<i>Apuleia praecox</i> .....	Yhvihra-pere	Paraguay	Bark 11
<i>Arctostaphylos uva-ursi</i> .....	Bearberry	Russia	Leaves and twigs 14
<i>Areca catechu</i> .....	Betelnut palm	India	Fruits 10-15
<i>Aspidosperma polyneuron</i> .....	Palo rosa	Paraguay	Bark 3



## SOURCE AND TANNIN CONTENT OF VEGETABLE TANNING MATERIALS.—(Continued)

Botanical name	Common name	Place grown	Per cent tannin
<i>Aspidiosperma quebracho-blanco</i> .....	White quebracho	Argentina	Leaves 27-28 Bark 4 Wood 3
<i>Banksia integrifolia</i> .....	Coast honeysuckle	Queensland	Bark 11
<i>Banksia serrata</i> .....	Heath honeysuckle	Australia	Bark 11-23
<i>Bauhinia vahlii</i> .....	Muhurain bark	India	Bark 9
<i>Betula alba</i> .....	White birch	Northern Europe	Bark 2-18
<i>Betula lenta</i> .....	Black birch	Northern America	Bark 3-18
<i>Boswellia serrata</i> .....	Salai bark	India	Bark 13
<i>Bruguiera gymnorrhiza</i> .....	Mangrove	East Africa	Bark 22-52
<i>Bruguiera parviflora</i> .....	Hagalay	Philippines	Bark 7-13
<i>Bruguiera rumphii</i> .....	Mangrove	New Caledonia	Bark 27-42 Root bark 6 Root wood 9
<i>Bumelia obtusifolia</i> .....	Pihkasurembiu	Paraguay	Bark 8
<i>Byrsonima cydoniaefolia</i> .....	Mureci	Bolivia	Bark 20
<i>Byrsonima spicata</i> .....	Tamwood	South America	Bark 44
<i>Cabrlea</i> sp.....	Cancharana	Paraguay	Bark 5
<i>Caesalpinia brevifolia</i> .....	Algarobilla	Chile	Pods 43-67
<i>Caesalpinia cacolaco</i> .....	Cascalote	Mexico	Pods 40-55
<i>Caesalpinia coriaria</i> .....	Divi-divi	Central America	Pods 30-50
<i>Caesalpinia digyna</i> .....	Tari	India and Burma	Pod cases 40-60
<i>Caesalpinia melanocarpa</i> .....	Guyacan	Argentina	Pods 15-23 Wood 8
<i>Caesalpinia tinctoria</i> .....	Celavinia	Central America	Pods 30-32
<i>Callitris calcarata</i> .....	Australian fir	Australia	Bark 17-31
<i>Callitris glauca</i> .....	Australian fir	Australia	Bark 12-15
<i>Camellia thea</i> .....	Tea	Asia and Africa	Leaves 5-10
<i>Carissa spinarum</i> .....		India	Leaves 8-12
<i>Cassia auriculata</i> .....	Tarwar	India	Bark 16-22
<i>Cassia fistula</i> .....	Amaltas	South India	Bark 11-15 Pod husk 17
<i>Castanea pubinervis</i> .....	Japanese chestnut	Japan	Bark 6 Wood 7
<i>Castanea vesva</i> .....	Spanish chestnut	Southern Europe Southern U. S.	Bark 6-8 Wood 7-11
<i>Castanopsis chrysophylla</i> .....	Western chinquapin	Pacific states	Bark 8
<i>Castanopsis sinensis</i> .....	Gie-gay	Indo-China	Bark 12
<i>Casuarina</i> .....	Ironwood	New Caledonia	Bark 10
<i>Casuarina equisetifolia</i> .....	Casagha pine	Southern Asia	Bark 11-18
<i>Casuarina glauca</i> .....	Bull oak	New South Wales	Bark 12
<i>Ceanothus velutina</i> .....	Snow bush	Western U. S.	Leaves 17
<i>Ceriops candolleana</i> .....	Bahau	India and Africa	Bark 24-42
<i>Ceriops roxburghiana</i> .....	Goran	India	Bark 13
<i>Ceriops tagal</i> .....	Tangal	Philippines	Bark 24-37
<i>Cleistanthus collinus</i> .....	Kodarsi		Bark 33
<i>Cocos romanzoffiana</i> .....	Pindo	Paraguay	Bark 7
<i>Copaifera lansdorfii</i> .....	Kupaih	Paraguay	Bark 17
<i>Coriaria myrtifolia</i> .....	French sumac	France	Leaves 15
<i>Coriaria nepalensis</i> .....		India	Leaves 20
<i>Coriaria ruscifolia</i> .....	Tutu	New Zealand	Bark 16-17
<i>Corylus avellana</i> .....	Hazel	Europe	Bark 5
<i>Coulteria tinctoria</i> .....	Tara	Algeria and Peru	Pods 43-51
<i>Crossostylis multiflora</i> .....	Bush mangrove	New Caledonia	Wood 21 Bark 3
<i>Cryptomeria japonica</i> .....	Japanese cedar	Japan	Bark 6
<i>Cupania</i> sp.....	Cedrillo	Paraguay	Bark 16
<i>Cupania uraguensis</i> .....	Kambuata	Paraguay	Bark 18
<i>Cupania vernalis</i> .....	Yaguarataih	Paraguay	Bark 15
<i>Dalbergia</i> sp.....	Yhsapih-ih	Paraguay	Bark 6
<i>Dioscorea atropurpurea</i> .....	Cu-nao	Indo-China	Tubers 20
<i>Elaeocarpus grandis</i> .....	Blue fig bark	New South Wales	Bark 10
<i>Elephantorrhiza burchellii</i> .....	Elephant roots	Africa	Root 6-22
<i>Enterolobium timbowwa</i> .....	Timbo	Paraguay	Bark 22

## SOURCE AND TANNIN CONTENT OF VEGETABLE TANNING MATERIALS.—(Continued)

Botanical name	Common name	Place grown	Per cent tannin
<i>Eremophila longifolia</i> .....	Emu bush	New South Wales	{ Bark 5 Leaves 10
<i>Eucalyptus accedens</i> .....	Spotted gum	Australia	Bark 18
<i>Eucalyptus alba</i> .....	Mountain gum	Australia	Bark 30-32
<i>Eucalyptus amygdalina</i> .....	Ribbon gum	New South Wales	Gum 58-65 Gum 28
<i>Eucalyptus corymbosa</i> .....	Bloodwood	New South Wales	{ Leaves 18 Bark 6
<i>Eucalyptus diversicolor</i> .....	Karri	Australia	Bark 16-20
<i>Eucalyptus erythronema</i> .....	White mallet	Australia	Bark 30
<i>Eucalyptus falcata</i> .....	Silver mallet	Australia	Bark 5-32
<i>Eucalyptus globulus</i> .....	Eucalyptus	Australia	Sap 28
<i>Eucalyptus gunnii</i> .....	Red gum	New South Wales	{ Leaves 17 Bark 11
<i>Eucalyptus longifolia</i> .....	Woolly-butt	Australia	Bark 8
<i>Eucalyptus maculata</i> .....	Spotted gum	New South Wales	{ Gum 45 Bark 10
<i>Eucalyptus loxophleba</i> .....	York gum	Australia	Leaves 5
<i>Eucalyptus obliqua</i> .....	Stringy bark	New South Wales	Bark 5-10
<i>Eucalyptus occidentalis</i> .....	Black mallet	Australia	Bark 17
<i>Eucalyptus occidentalis astringens</i> .....	Red mallet	Australia	Bark 20-26
<i>Eucalyptus odorata</i> .....	White box	New South Wales	Bark 40-50
<i>Eucalyptus piperita</i> .....	Messmate	New South Wales	Leaves 7
<i>Eucalyptus platypus</i> .....	Round leaf moort	Australia	{ Gum 32-62 Leaves 13
<i>Eucalyptus redunca</i> .....	Wandoo	Australia	Bark 25
<i>Eucalyptus redunca oxymitra</i> .....	Blue leaf mallet	Australia	Bark 16-20
<i>Eucalyptus robusta</i> .....	Mahogany	Florida	Bark 22-30
<i>Eucalyptus rostrata</i> .....	Blue gum	Australia	Leaves 12-17
<i>Eucalyptus salmonophloia</i> .....	Salmon gum	Australia	Bark 16
<i>Eucalyptus salubris</i> .....	Gimlet	Australia	Bark 8-13
<i>Eucalyptus siderophloia</i> .....	Red iron bark	New South Wales	{ Bark 16-19 Gum 35-73
<i>Eucalyptus sieberiana</i> .....	Cabbage gum	New South Wales	Bark 10
<i>Eucalyptus spathulata</i> .....	Swamp mallet	Australia	{ Leaves 6 Bark 37
<i>Eucalyptus stellulata</i> .....	Black gum	New South Wales	Bark 26
<i>Eucalyptus stuartiana</i> .....	Apple	New South Wales	{ Bark 13 Leaves 17
<i>Eucalyptus torquata</i> .....	Flowering gum	Australia	Bark 5
<i>Eucalyptus viminalis</i> .....	Manna gum	New South Wales	{ Leaves 10 Bark 17
<i>Eugenia braziliensis</i> .....	Yhva-poroitih	Paraguay	Bark 8
<i>Eugenia jambolana</i> .....	Java plum	India	{ Leaves 4 Bark 43
<i>Eugenia jambos</i> .....		Brazil	Leaves 17
<i>Eugenia maire</i> .....		New Zealand	Wood 12
<i>Eugenia michellii</i> .....	Nangapirih gwazu	Paraguay	Bark 19
<i>Eugenia pungens</i> .....	Yhva viyu	Paraguay	Bark 12
<i>Eugenia smithii</i> .....		Australia	Bark 16-17
<i>Eugenia sp.</i> .....	Yhvajhay puihta gwazu	Paraguay	Bark 29
<i>Exocarpus cupressiformis</i> .....	Native eherry	Australia	Bark 11
<i>Ficus sp.</i> .....	Kili bark	Sudan	Bark 17
<i>Fusanus acuminatus</i> .....	Quandony	Australia	Bark 16-29
<i>Garcinia mangostana</i> .....	Mangoustan	Cochin-China	Bark 15-16
<i>Grevillia striata</i> .....	Beefwood	Australia	Bark 19
<i>Guarea sp.</i> .....	Guare	Paraguay	Fruit shells 14
<i>Hakea glabella</i> .....		Australia	Bark 18
<i>Hakea leucoptera</i> .....	Needle bark	New South Wales	Bark 10
<i>Heritiera fomes</i> .....	Sundri bark	India	Bark 18
			Bark 11
			Bark 7



## SOURCE AND TANNIN CONTENT OF VEGETABLE TANNING MATERIALS.—(Continued)

Botanical name	Common name	Place grown	Per cent tannin
<i>Hopea odorata</i> .....		India	Bark 14-15 Leaves 11 Wood 10
<i>Hopea parviflora</i> .....	Ironwood	India	Bark 17-22
<i>Hydnora longicollis</i> .....	Ganib	Africa	Roots 32
<i>Inga affinis</i> .....	Inga gwazu	Paraguay	Bark 26
<i>Inga feuillei</i> .....	Paypay	Peru	Pods 12-15
<i>Juniperus recurva</i> .....	Weeping blue	Japan	Bark 8
<i>Krameria triandria</i> .....	Rhatany	Peru	Root bark 20
<i>Larix dahurica</i> .....	Larch	Japan	Bark 9
<i>Larix europaea</i> .....	Larch	Europe	Bark 9-10
<i>Larix occidentalis</i> .....	Western larch	N. W. United States	Bark 11 Wood 7
<i>Laurus lingue</i> .....		Chile	Bark 17-19
<i>Leuceadendron argenteum</i> .....	Silver tree	Cape Good Hope	Bark 9-16
<i>Leucospermum conocarpum</i> .....	Knotted tree	Cape Good Hope	Bark 10-22
<i>Ludwigia caparossa</i> .....	Caparossa	Brazil	Bark 20-25
<i>Lysiloma candida</i> .....	Palo blanco	Lower California	Bark 26
<i>Maclura pomifera</i> .....	Osage orange	Texas	Wood 11
<i>Malpighia faginea</i> .....	Nance	Mexico	Bark 26
<i>Malpighia punicifolia</i> .....	Mangrutta	Nicaragua	Bark 20-30
<i>Mimosa farinosa</i> .....	Mimosa	Argentina	Bark 4
<i>Mimosa pudica</i> .....	Mimosa	India	Roots 10
<i>Mimosa sp.</i> .....	Yukeri gwazu	Paraguay	Bark 11
<i>Myrica asplenifolia</i> .....	Sweet fern	Michigan	Leaves 4-5 Roots 4-6
<i>Myrica nagi</i> .....	Box myrtle	India	Bark 13-27
<i>Nauclea gambir</i> .....	Gambier	East Indies	Leaves and twigs 5-6
<i>Ocotea bullata</i> .....		South Africa	Bark 6
<i>Ocotea sp.</i> .....	Yhva-iha	Paraguay	Bark 11
<i>Osyris abyssinica</i> .....		Transvaal	Leaves and twigs 13-25
<i>Osyris arborea</i> .....		Northern India	Leaves 20
<i>Osyris compressa</i> .....	Cape sumac	Cape Good Hope	Leaves 17-23
<i>Oxalis gigantea</i> .....		Chile	Bark 25
<i>Paullinia sorbilis</i> .....	Guara	Brazil	Fruit 43-55
<i>Peltophorium dubium</i> .....	Yhvihra puihta	Paraguay	Bark 31
<i>Pentacme suavis</i> .....		India	Leaves 12-24 Bark 7-13 Wood 4 Stoned fruit 26-35
<i>Phyllanthus emblica</i> .....	Amla	India	Leaves 23-28 Bark 15-24
<i>Phyllocladus asplenifolia</i> .....	Celery-topped pine	Tasmania	Bark 23
<i>Phyllocladus rhomboidalis</i> .....		Tasmania	Bark 21
<i>Phyllocladus trichomanoides</i> .....		New Zealand	Bark 28-30
<i>Picea glehni</i> .....	Red yezomatsu	Japan	Bark 19
<i>Picea sitchensis</i> .....	Sitka spruce	Pacific states	Bark 12-18
<i>Pinus cembra</i> .....	Pine	Alpine Europe	Bark 3-5
<i>Pinus densiflora</i> .....	Red pine	Japan	Bark 6
<i>Pinus halepensis</i> .....	Aleppo pine	Mediterranean coasts	Bark 10-15
<i>Pinus Khasya</i> .....	Pine	Burma	Bark 7-10
<i>Pinus longifolia</i> .....	Long-leaved pine	India	Bark 11-14
<i>Pinus muricata</i> .....	Swamp pine	California	Bark 13
<i>Pinus radiata</i> .....	Monterey pine	California	Bark 14
<i>Pinus sylvestris</i> .....	Scotch fir	Northern Europe	Bark 4-5
<i>Pinus thunbergii</i> .....	Black pine	Japan	Bark 6
<i>Piptadenia cebil</i> .....		Argentina	Bark 15
<i>Piptadenia rigida</i> .....	Kurupaih-ra puihta	Paraguay	Bark 28
<i>Pistacia lentiscus</i> .....	Pistacio	Mediterranean	Leaves 12-19
<i>Pistacia orientalis</i> .....	Pistacio	India	Galls 30-40
<i>Pithecolobium dulce</i> .....	Camanchile	Mexico	Bark 15-25
<i>Polygonum amphibium</i> .....		Missouri	Roots 22 Branches 17
<i>Polygonum bistorta</i> .....	Snakeweed	England	Roots 16-21

## SOURCE AND TANNIN CONTENT OF VEGETABLE TANNING MATERIALS.—(Continued)

Botanical name	Common name	Place grown	Per cent tannin
<i>Populus tremula</i> .....	Poplar	Europe	Bark 3
<i>Prosopis oblonga</i> .....	Abu-surug	Sudan	Bark 14
<i>Protea grandiflora</i> .....		Cape Good Hope	Bark 15-16
<i>Protea mellifera</i> .....	Sugarbush	Cape Good Hope	Bark 18-25
<i>Pseudotsuga taxifolia</i> .....	Douglas fir	Pacific states	Bark 7
<i>Punica granatum</i> .....	Pomegranate	India	{ Fruit rind 27-30 Kernel 32 Bark 18-22 Wood 20-30 Bark 6-8
<i>Quebrachia lorentzii</i> .....	Quebracho	South America	{
<i>Quercus aegilops</i> .....	Valonia	Mediterranean	Acorns 17-40
<i>Quercus agrifolia</i> .....	Live oak	California	Bark 19
<i>Quercus alba</i> .....	White oak	Northern America	Bark 7
<i>Quercus californica</i> .....	Black oak	California	Bark 10
<i>Quercus cerris</i> .....	Turkey oak	Southern Europe	Galls 35
<i>Quercus chrysolepis</i> .....	Maul oak	Pacific states	Bark 7-12
<i>Quercus coccifera</i> .....	Kermes oak	Mediterranean	Bark 10-18
<i>Quercus coccinea</i> .....	Scarlet oak	United States	Bark 8
<i>Quercus densiflora</i> .....	Tanbark oak	California	Bark 10-29
<i>Quercus dentata</i> .....	Japanese oak	Japan	{ Bark 11 Wood 7
<i>Quercus fenestrata</i> .....		Northern India	Bark 10-16
<i>Quercus garryana</i> .....	Pacific post oak	Pacific states	Bark 6-7
<i>Quercus grosseserrata</i> .....	Water oak	Japan	{ Bark 9 Wood 2
<i>Quercus ilex</i> .....	Evergreen oak	Southern Europe	Bark 5-11
<i>Quercus incana</i> .....		India	Bark 22
<i>Quercus infectoria</i> .....	Aleppo	Turkey	Galls 24-60
<i>Quercus lamellosa</i> .....		Northern India	Bark 8-10
<i>Quercus lineata</i> .....		Northern India	Bark 11
<i>Quercus lobata</i> .....	White oak	California	Bark 12
<i>Quercus mirbeckii</i> .....		Algeria	Bark 8
<i>Quercus pachyphylla</i> .....	Sungra katus	Northern India	{ Acorn cups 13-15 Bark 12-13 Leaves 10
<i>Quercus prinus</i> .....	Chestnut oak	United States	Bark 9-12
<i>Quercus pseudocornea</i> .....	Gie-quang	Indo-China	Bark 16
<i>Quercus robur</i> .....	Common oak	Europe and U. S.	{ Bark 9-12 Wood 2-4
<i>Quercus rubra</i> .....	Red oak	Northern America	{ Twig galls 35 Bark 4-6
<i>Quercus spp.</i> .....	Gie-bob	Indo-China	Bark 11
<i>Quercus suber</i> .....	Cork oak	Europe	Bark 12-19
<i>Quercus tozae</i> .....		Southern France	Bark 14
<i>Quercus velutina</i> .....	Black oak	United States	Bark 6-12
<i>Quercus wislizeni</i> .....	Highland oak	California	Bark 7-8
<i>Rheedia braziliensis</i> .....	Pakuri	Paraguay	Bark 22
<i>Rhizophora conjugata</i> .....	Mangrove	Philippines	Bark 26-32
<i>Rhizophora mangle</i> .....	Mangrove	Tropical coasts	{ Bark 15-42 Leaves 22
<i>Rhizophora mucronata</i> .....	Mangrove	Asia and Africa	Bark 21-48
<i>Rhus copallina</i> .....	Sumac	United States	Leaves 17-35
<i>Rhus coriaria</i> .....	Sicilian sumac	Sicily	Leaves 25-52
<i>Rhus cotinus</i> .....	Venetian sumac	Italy	Leaves 17
<i>Rhus cotinoides</i> .....	Sumac	United States	Leaves 21
<i>Rhus glabra</i> .....	White sumac	United States	Leaves 15-25
<i>Rhus metopium</i> .....	Sumac	United States	Leaves 8
<i>Rhus mysorensis</i> .....		Southern India	Bark 20
<i>Rhus pentaphylla</i> .....	Tizra sumac	Morocco	{ Roots 29 Wood 23
<i>Rhus rhodanthema</i> .....	Deep yellow wood	New South Wales	Bark 23
<i>Rhus semialata</i> .....	Sumac	America and Asia	{ Leaves 5 Chinese galls 70



## SOURCE AND TANNIN CONTENT OF VEGETABLE TANNING MATERIALS.—(Continued)

Botanical name	Common name	Place grown	Per cent tannin
<i>Rhus succedanea</i> .....	Sumac	India	Leaves 20
<i>Rhus thunbergii</i> .....		Cape Good Hope	Bark 28
<i>Rhus typhina</i> .....	Virginian sumac	Virginia	Leaves 10-18
<i>Robinia pseudacacia</i> .....	Black locust	Europe	{ Bark 2-7 Wood 3-4
<i>Rollinia</i> sp.....	Aratiku gwazu	Paraguay	Bark 4
<i>Rumex hymenosepalum</i> .....	Canaigre	Mexico	Roots 25-30
<i>Rumex maritima</i> .....	Docks	Europe	Roots 22
<i>Sabal palmetto</i> .....	Cabbage palmetto	Florida	Roots 10-18
<i>Sabal serrulata</i> .....	Saw palmetto	Florida	Leaves 13
<i>Salix alba</i> .....	White willow		Bark 9
<i>Salix arenaria</i> .....	Willow	Russia	Bark 13
<i>Salix caprea</i> .....	Willow	Japan	Bark 8-12
<i>Salix fragilis</i> .....	Willow		Bark 9-12
<i>Salix lasiandra</i> .....	Yellow willow	California	Bark 2
<i>Salix purpurea</i> .....	Willow	Japan	Bark 8
<i>Salix viminalis</i> .....	Willow	Russia	Bark 7-10
<i>Schinus molle</i> .....	Molle	Argentina	Leaves 19
<i>Sequoia sempervirens</i> .....	Redwood	Pacific states	{ Heartwood 4-12 Sapwood 1-2 Bark 1-3
<i>Shorea obtusa</i> .....		India	{ Bark 9 Wood 6-7
<i>Shorea robusta</i> .....	Sal bark	India	Bark 6-15
<i>Sonneratia pagatpat</i> .....	Pagatpat	Philippines	Bark 11-12
<i>Spermolepsis gummifera</i> .....	Oak gum	New Caledonia	{ Bark 17 Resin 43-80
<i>Statice coriaria</i> .....	Marsh rosemary	Southern Russia	Roots 20-22
<i>Stryphnodendron barbatimao</i> .....	Barbatimao	Brazil	Bark 18-27
<i>Tamarix africana</i> .....	Tamarisk	Mediterranean	{ Galls 26-56 Twigs 9 Leaves 9
<i>Tamarix articulata</i> .....	Tamarisk	Morocco	Galls 43-56
<i>Tamarix dioica</i> .....	Jhao	India	Bark 10
<i>Taxus cuspidata</i> .....	Yew	Japan	Bark 10
<i>Terminalia arjuna</i> .....	Kahua	India	Bark 18-24
<i>Terminalia belerica</i> .....	Bedda	India	Nuts 12
<i>Terminalia catappa</i> .....	Badamier	India	Bark 12-25
<i>Terminalia chebula</i> .....	Myrobalan	India	Nuts 30-40
<i>Terminalia glabra</i> .....	Kumbuk	Ceylon	Bark 27-32
<i>Terminalia mauritiana</i> .....	Jamrosa	India	Bark 30
<i>Terminalia oliveri</i> .....	Thann	Malay	{ Bark 31 Leaves 14
<i>Tormentilla erecta</i> .....		Europe	Roots 20-46
<i>Trichilia catigua</i> .....	Kaatigua puihta	Paraguay	Bark 21
<i>Trichilia hieronymi</i> .....	Kaatigua moroti	Paraguay	Bark 23
<i>Tsuga canadensis</i> .....	Hemlock	Northern America	Bark 7-12
<i>Tsuga heterophylla</i> .....	Western hemlock	Pacific states	Bark 9-16
<i>Umbellularia californica</i> .....	California laurel	California	Bark 16
<i>Vateria indica</i> .....		India	Fruit 25
<i>Weimannia glabra</i> .....	Curtidor	Venezuela	Bark 10-13
<i>Woodfordia floribunda</i> .....	Itcha	India	{ Bark 27 Leaves 15
<i>Ximenia americana</i> .....	Alimu	Sudan	Bark 17
<i>Xylia dolabriformis</i> .....	Jamba	Burma and India	{ Bark 9-19 Wood 4
<i>Xylocarpus granatum</i> .....	Piagao	Africa and Asia	Bark 21-48
<i>Xylocarpus obovatus</i> .....	Tabique	Philippines	Bark 22-25
<i>Zizyphus nummularia</i> .....	Ber	India	Bark 10
<i>Zizyphus xylopyra</i> .....	Gothar	India	Fruit flesh 23

LITERATURE

(For a key to the periodicals see end of volume)

The following periodicals, reports and books were used in the above compilation: 45; 54; 157; 257; 258; 259; 260; 261; 262; 263; 264; 265; *Reports*, Freiberg Experiment Station; *Reports*, Australian Institute of Science and Industry; U. S. Department of Commerce, *Reports*; H. R. Procter, *Principles of Leather Manufacture*, New York, 1922; J. Dekker, *Die Gerbstoffe*, Berlin, 1913; A. Harvey, *Tanning Materials*, London, 1921; J. A. Wilson, *The Chemistry of Leather Manufacture*, New York, 1923.

Electrical Potential Difference (P. D.) between Tannin Particles and Solutions of Tanning Extracts

1. EXTRACTS FROM DIFFERENT SOURCES

Extract of	Concn. g dry solids per l	P. D. (volts)
Gambier.....	18.7	-0.005
Oak bark.....	17.0	-0.009
Chestnut wood.....	17.8	-0.009
Hemlock bark.....	16.7	-0.010
Sumac leaves.....	19.6	-0.014
Spruce bark.....	19.5	-0.018
Osage orange wood.....	13.7	-0.018 (?)
Quebracho wood.....	11.0	-0.028

2. EFFECT OF REMOVAL OF NONTANNIN BY DIALYSIS

Extract of	Initial concn. g dry solids per l	Hours dialyzed	Final concn. g dry solids per l	P. D. (volts)
Gambier.....	32.8	24	21.0	-0.029
Hemlock bark.....		24		-0.024
Sumac leaves.....	16.0	24	8.6	-0.026
Osage orange.....	16.0	24	10.9	-0.024
Quebracho wood.....	16.0	60	9.6	-0.033

3. EFFECT OF CONCENTRATION OF QUEBRACHO EXTRACT

Concn. g dry solids per l	P. D. (volts)
4.0	-0.030
8.0	-0.029
16.0	-0.028
32.0	-0.024

4. EFFECT OF ADDITION OF ACID  
(16 g solid quebracho extract per l)

0.1N HCl added per l	P. D. (volts)
0.0	-0.024
10.0	-0.014
15.0	-0.010
20.0	approx. zero

LITERATURE

Thomas and Foster, 45, 14: 191; 22. 15: 707; 23.

LEATHER

JOHN ARTHUR WILSON

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Tensile strength, elongation and resistance to stitch tear.  
  
Absorption of water from moist air.  
Swelling by water.  
Permeability to water vapor and to air.  
Resilience.

MATIÈRES

Genres de cuirs étudiés.  
Composition.  
Résistance à la traiction, allongement et résistance au déchirement du point de couture.  
  
Absorption de l'eau à partir de l'air humide.  
Gonflement à l'eau.  
Perméabilité à la vapeur d'eau et à l'air.  
Rejailissement.

INHALTSVERZEICHNIS

Die untersuchten Lederarten.  
Zusammensetzung.  
Reissfestigkeit, Dehnbarkeit, Nähfestigkeit.  
  
Wasseraufnahme aus feuchter Luft.  
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TYPE

GENRES DE CUIRS

- IND. No.
1. Colored, vegetable-tanned calf.
  2. Colored, chrome-tanned calf.
  3. Black, chrome-tanned, glazed kid.
  4. Black, chrome-tanned kangaroo.
  5. Black, vegetable-tanned horse butt (Cordovan).
  6. Colored, chrome-tanned, buffed and split cow hide (buck).
  7. Colored, chrome-tanned side (split cow hide).

1. Veau teint, tanné au végétal.
2. Veau teint, tanné au chrome.
3. Chevreau verni, noir, tanné au chrome.
4. Kangourou noir, tanné au chrome.
5. Croupon de cheval, tanné au végétal (Cordovan).
6. Cuir de vache teint, tanné au chrome, refendu et effleuré (façon daim).
7. Bande entière de vache (refendue) teinte, tannée au chrome.

DIE UNTERSUCHTEN LEDERARTEN

1. Farbiges lohgaes Kalbleder.
2. Farbiges Chromkalbleder.
3. Schwarzes Chromchevreaux.
4. Schwarzes chromgaes Känguruhleder.
5. Schwarzer lohgaes Rosspiegel (Cordovan).
6. Farbige chromgaes, gebuffte Rindernarbenspalte (buck).
7. Farbige chromgaes Rindspalte.

TIPDI PELLE

1. Vitello al tannino, colorato.
2. Vitello al eromo, colorato.
3. Cuoio morbido di montone; glacé tinto in nero al cromo.
4. Pelle di canguro al cromo, tinta in nero.
5. Culatta di cavallo al tannino tinta in nero (Cordovano).
6. Pelle di vacca al cromo, spaccata, scamosciata, colorata.
7. Fianco di vacca (spaccata) al cromo, colorato.



8. Black, chrome-tanned slink calf (suede).	Veau mort-né noir, tanné au chrôme (façon suède).	Schwarzes chromgare Kalbleder (suède).	Pelle di vitello (feto) al cromo, tinta in nero (tipo svedese).
9. Uncolored, vegetable-tanned calf (shoe lining).	Veau naturel, tanné au végétal (doublure de chaussure).	Ungefärbtes lohgate Kalbleder (Schuhfutterleder).	Vitello al tannino in color naturale (fodera da calzature).
10. Uncolored, vegetable-tanned sheep (shoe lining).	Mouton naturel, tanné au végétal (doublure de chaussure).	Ungefärbtes lohgate Schafleder (Schuhfutterleder).	Montone al tannino in color naturale (fodera da calzature).
11. Black, vegetable-tanned shark.	Requin noir, tanné au végétal.	Schwarzes lohgate Haifischleder.	Pelle di squalo al tannino, tinta in nero.
12. Patent, chrome-tanned side (split cow hide).	Bande entière de vache (refendue), vernie, tannée au chrôme.	Chromgares Rindspaltlackleder.	Fianco di vacca (spaccata) al cromo, brevettato.
13. Patent, chrome-tanned kid.	Chevreau verni, tanné au chrôme.	Chromchevreauxlackleder.	Cuoio morbido di montone al cromo, brevettato.
14. Patent, chrome-tanned colt.	Poulain verni, tanné au chrôme.	Chromgares Rosslackleder.	Puledro al cromo, brevettato.
15. Heavy, black, chrome-tanned cow hide.	Cuir de vache, fort, noir, tanné au chrôme.	Schweres schwarzes Chromrindleder.	Pelle di vacca al cromo tinta in nero, pesante.
16. Chrome-re-tan, army upper leather (split cow hide).	Cuir d'empaigne pour l'armée, semi-chrôme (peau de vache refendue chrômé, puis retanné au végétal).	Nachchromiertes Militäroberleder (Rindspalte).	Cuoio di vacca (spaccata) superiore per l'esercito, riconciato al cromo.
17. Vegetable-tanned steer hide (sole leather).	Cuir de génisse, tanné au végétal (cuir de semelles).	Lohgares Rindleder (Sohlenleder).	Pelle di giovenco al tannino (cuoio da suola).
18. Chrome-tanned steer hide (sole leather).	Cuir de génisse, tanné au chrôme (cuir de semelles).	Chromgares Rindleder (Sohlenleder).	Pelle di giovenco al cromo (cuoio da suola).

Each analysis was made on one representative skin of each type. The same 18 skins were used to make all measurements listed in this section, thus making all properties of any one type directly comparable and related to chemical composition.

Chaque analyse a été effectuée sur une peau représentative de chaque genre de cuir. On a utilisé les mêmes 18 peaux pour faire toutes les mesures mentionnées dans cette section. De la sorte, toutes les propriétés de chaque genre de cuir sont directement comparables et en relation avec la composition chimique.

Jede Analyse wurde an einem besonderem Vertreter einer Hauttype gemacht. Dieselben 18 Häute sind für alle Messungen die in diesem Abschnitt angeführt werden, verwendet worden. Es werdendadurch alle Eigenschaften jeder einzelnen Type direkt vergleichbar und in Beziehung zur chemischen Zusammensetzung gebracht.

Ogni analisi fu fatta sopra un campione rappresentante ciascun tipo di pelle. Gli stessi 18 campioni furono usati per eseguire tutte le misure indicate in questa sezione, risultando così tutte le proprietà di ogni singolo tipo direttamente paragonabili ed in rapporto alla composizione chimica.

COMPOSITION, % AT 50% RELATIVE HUMIDITY (1)													
Ind. No.	H <sub>2</sub> O	Skin protein	Fat	H <sub>2</sub> SO <sub>4</sub>	Na <sub>2</sub> SO <sub>4</sub>	HCl	NaCl	CaO	MgSO <sub>4</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	Cr <sub>2</sub> O <sub>3</sub>	Other organic matter by diff.
1	13.6	41.0	12.0	0.3						0.4	0.1		23.5
2	16.3	62.6	4.6	3.4	0.4	0.3	0.5			1.2	0.3	5.4	5.0
3	13.7	65.3	6.6	1.0	0.9	0.5	0.2	0.2		0.2	0.3	4.5	6.6
4	12.0	62.7	11.3	1.8	0.2	0.3	0.1	0.3		0.1	0.1	6.0	5.1
5	10.0	40.1	18.6	0.6				0.1			0.1		8.7
6	14.1	69.6	2.1	3.2	0.3			0.2		1.0	0.6	5.3	21.8
7	16.3	66.8	5.8	3.6	1.0		0.3	0.1		0.2	0.2	3.6	3.6
8	12.7	55.1	7.1	0.8	0.4	0.2	0.1	0.2		1.0	1.2	5.4	2.1
9	11.9	46.0	7.6	0.1				0.2		0.1			15.8
10	10.9	50.0	6.1	1.7		0.6		0.1		0.1	0.1		21.8
11	12.2	45.4	6.9	1.5				0.1			0.1		17.4
12	10.1	50.5	10.0	1.8	0.6	0.1		0.1		0.1	0.4	2.9	28.4
13	11.8	54.0	6.6	2.1	0.3			0.2		0.2	0.6	3.6	9.0
14	12.0	60.4	5.1	2.3	0.5	0.1	0.1	0.3		0.1	0.3	3.6	8.4
15	14.4	57.0	14.2	4.4	0.4	0.1	0.4				0.7	5.5	6.1
16	15.1	44.6	20.4	1.1	0.3		0.4			0.3	0.2	2.4	9.1
17	14.6	29.7	3.2	0.8				0.8		0.7			2.9
18	16.3	29.4	25.4	5.9	12.3	0.8	0.9	2.3	0.5	2.6	0.5	1.7	15.2
													14.6
													1.4

#### TENSILE STRENGTH, STRETCH AND STITCH TEAR (1)

Each value recorded is the average of 3 determinations. The strips for strength and stretch were cut with a die 2.54 × 15.24 cm and the jaws of the testing machine were initially 10.16 cm apart. The 3 strips from each skin were cut with their lengths parallel to the backbone and spaced equally between head and tail end along a

line midway between backbone and belly edge. The leather was in equilibrium with an atmosphere of 50% relative humidity. The stitch tear was made with Irish flax shoe thread No. 6 slipped through a hole 2 mm from the leather edge.

$l$  = average thickness;  $TS$  = tensile strength in kg per cm<sup>2</sup> of original cross section;  $S$  = stretch ( $a$ ) at 13.6 kg per 2.54 cm width, ( $b$ ) at 225 kg per cm<sup>2</sup>;  $ST$  = stitch tear.

Ind. No.	$l$ mm	$TS$ kg/cm <sup>2</sup>	% $S$		$ST$ kg
			(a)	(b)	
1	1.19	422	5	17	13
2	1.00	327	7	22	10
3	0.76	409	20	34	8
4	0.52	508	16	24	9
5	1.12	113	14	53	7
6	0.92	201	9	34	5
7	1.22	213	11	36	10
8	0.63	156	19	36	1
9	0.93	310	11	27	8
10	0.87	200	13	35	6
11	0.80	118	35	84	5
12	1.09	90	10	69	3
13	0.96	217	17	42	7
14	1.43	228	13	46	8
15	2.94	182	8	54	27
16	2.48	346	6	29	28
17	6.28	191	1	23	38
18	4.80	100	1	70	21

## AREA CHANGE WITH RELATIVE HUMIDITY

Measurements were made after 30 days contact at 25°C. The samples were kept in desiccators over sulfuric acid solutions of 37.5, 17.6, 13.6, 11.8, 10.2, 6.6, and 0.0 normalities to maintain the relative humidities at 0, 20, 40, 50, 60, 80 and 100% respectively.

Ind. No.	% increase in area with increasing relative humidity					
	Relative humidity					
	20	40	50	60	80	100
1	3.6	4.2	4.5	4.8	5.5	5.7
2	7.7	10.0	10.3	11.5	12.4	16.0
3	3.4	4.6	4.8	5.5	7.5	15.6
4	5.7	6.9	6.9	7.5	10.9	19.0
5	2.0	3.0	3.0	3.2	3.4	4.0
6	6.7	7.5	7.7	8.8	10.5	14.7
7	6.7	7.7	8.0	9.2	10.5	15.8
8	8.0	10.7	10.9	11.7	11.9	13.8
9	5.3	6.5	6.7	6.9	7.5	9.2
10	4.2	5.5	5.5	5.9	8.2	9.4
11	4.0	4.9	5.1	5.3	5.7	8.0
12	5.5	6.3	6.3	6.9	8.6	10.5
13	5.3	5.9	6.1	6.5	7.1	9.6
14	4.5	6.3	6.3	6.5	8.2	13.0
15	7.1	8.0	8.0	9.2	10.9	16.9
16	6.5	7.7	8.0	8.4	9.0	11.5
17	1.0	1.4	2.7	3.0	3.0	5.5
18	3.8	4.5	5.9	6.3	7.7	13.0



FIG. 1.—Variations in strength and resistance to stretch for calf leather from different parts of the skin (3).

Tensile strength given in kg per cm<sup>2</sup>.

Percentage stretch measured under load of 225 kg per cm<sup>2</sup>.

□	Tensile strength less than 170 kg.	■	Tensile strength 260 to 350 kg.
▨	Stretch greater than 60 %.	▩	Stretch 26 to 20 %.
▧	Tensile strength 170 to 260 kg.	▪	Tensile strength greater than 350 kg.
▦	Stretch 60 to 26 %.	▫	Stretch less than 20 %.

## WATER CONTENT AT DIFFERENT RELATIVE HUMIDITIES (1, 2)

Ind. No.	g water per 100 g dry leather after 30 days at relative humidity of %						
	0	20	40	50	60	80	100
1	1.4	10.8	14.0	15.7	17.9	21.2	39.6
2	2.1	12.4	18.1	19.5	21.0	27.9	53.4
3	2.9	10.6	14.2	15.9	18.1	27.3	62.2
4	0.4	9.3	12.6	13.6	15.4	22.8	51.7
5	1.8	7.0	9.8	11.1	11.8	15.6	22.9
6	2.2	11.7	15.4	16.4	17.4	25.1	47.8
7	1.8	12.1	17.2	19.5	20.8	25.9	54.5
8	0.3	9.4	13.4	14.5	15.8	20.9	59.5

WATER CONTENT AT DIFFERENT RELATIVE HUMIDITIES (1, 2).—  
(Continued)

Ind. No.	g water per 100 g dry leather after 30 days at relative humidity of %						
	0	20	40	50	60	80	100
9	0.9	8.8	12.1	13.5	16.1	19.6	32.0
10	1.1	8.2	11.3	12.2	14.6	19.6	48.4
11	2.4	10.2	12.7	13.9	14.3	17.1	38.1
12	0.7	8.5	10.4	11.2	12.6	18.5	36.9
13	1.9	10.5	12.7	13.4	14.6	20.7	39.5
14	2.0	9.6	12.4	13.6	15.1	22.7	57.5
15	1.2	12.9	15.1	16.8	17.7	21.9	49.6
16	4.4	12.5	16.4	17.8	18.4	21.1	37.8
17	3.4	12.2	17.0	17.1	18.3	21.7	43.6
18	8.6	14.9	18.1	19.5	20.6	24.5	50.4

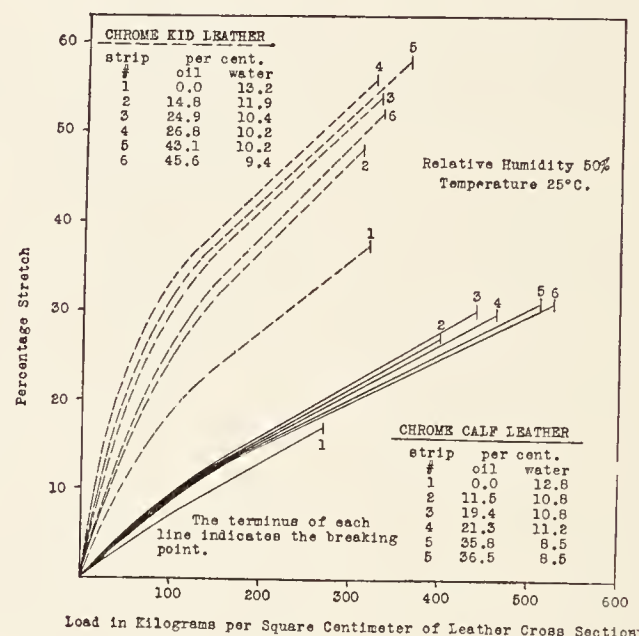


FIG. 2.—Effect of oil content (4).

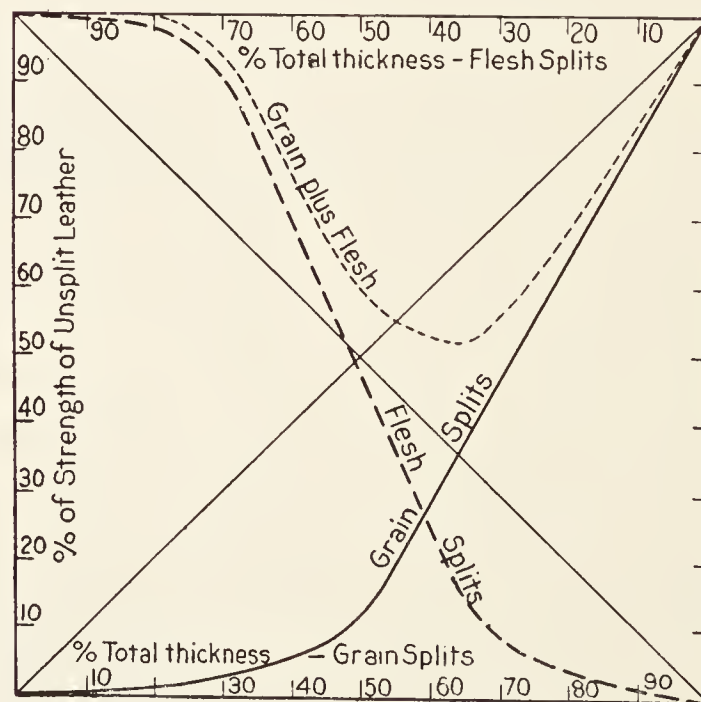


FIG. 3.—Relative strengths of splits of vegetable-tanned calf leather compared with unsplit leather. Average tensile strength of skin 324 kg/cm<sup>2</sup>; average thickness 0.91 mm. Strengths in chart are given per unit width, not cross section (5).



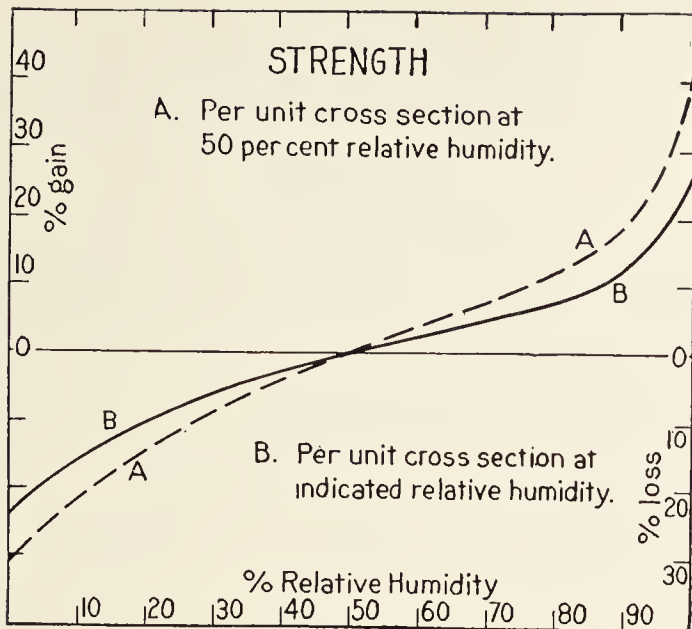


FIG. 4.—Percentage gain or loss in strength per unit cross section of chrome calf leather with change of relative humidity. The difference between the two curves reflects the volume change in the leather with relative humidity. Leather with high fat content shows much less change in strength with relative humidity (\*).

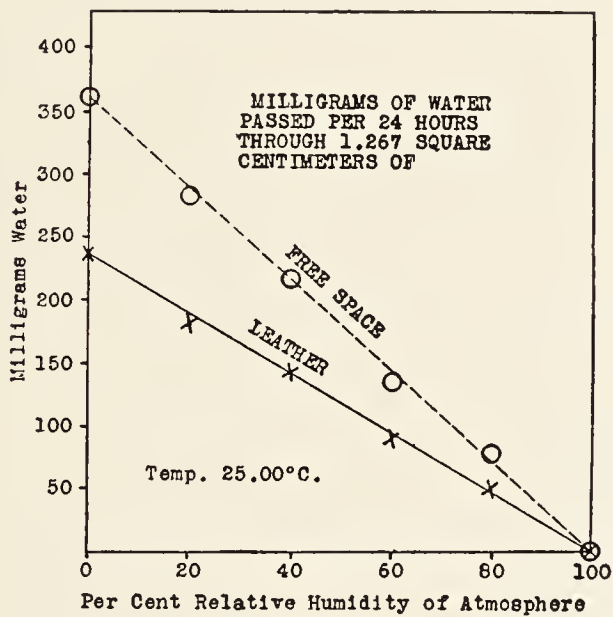


FIG. 5.—Effect of relative humidity of 1 atmosphere upon passage of water into it from an atmosphere kept at 100 % relative humidity through vegetable-tanned calf leather and through free space (\*).

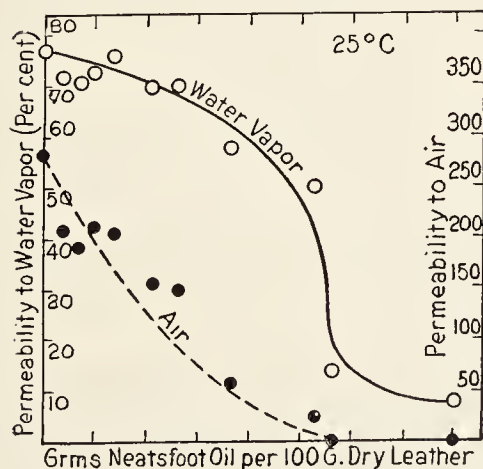


FIG. 7.—Effect of oil content of leather (\*).

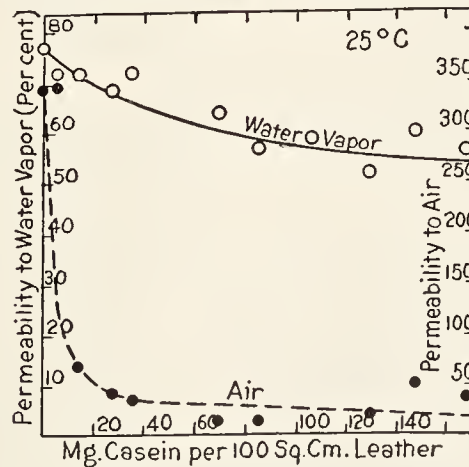


FIG. 8.—Effect of quantity of casein used as finishing material (\*).

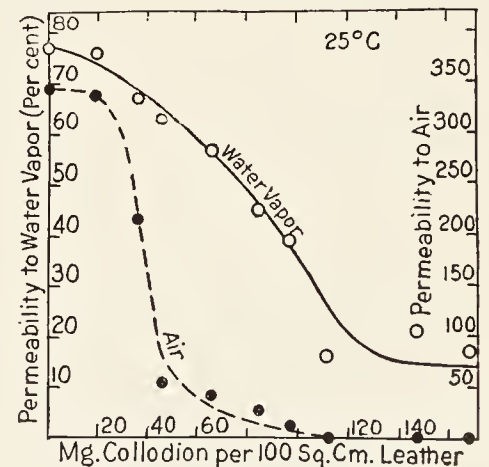


FIG. 9.—Effect of quantity of collodion used as finishing material (\*).

# VENTILATING PROPERTIES

Effect of kind of skin and tannage (1)

Ind. No.	1	2	3	4	5	6	7	8	9
1 mm.....	1.08	1.00	0.73	0.53	1.15	0.88	1.22	0.60	0.88
$P_w^*$ , %.....	70	70	70	65	54	95	74	97	79
$P_A^\dagger$ .....	197	67	249	185	41	1183	369	1820	246

Ind. No.	10	11	12	13	14	15	16	17	18
1 mm.....	0.88	0.89	1.01	0.99	1.37	2.59	2.31	6.28	4.80
$P_w^*$ , %.....	78	89	6	9	5	38	49	34	4
$P_A^\dagger$ .....	251	1416	0	0	0	45	179	43	0

\*  $P_w$ , % permeability to water vapor, is defined as 100 times the ratio of the rate of passage of water from an atmosphere of 100% relative humidity to one of zero humidity through a given area of the leather sample, of thickness, 1, to the rate of a similar passage of water through an equal area of free space at the same temperature. In these measurements, the area chosen was 1.267 cm<sup>2</sup> and the temperature 25°C.

†  $P_A$ , permeability to air, is defined as the rate of flow of air (cm<sup>3</sup>/min per cm<sup>2</sup> of leather) through thickness 1, under the pressure difference, atmospheric to 35 mm Hg.

Effect of temperature, Fig. 6; effect of relative humidity, Fig. 5.

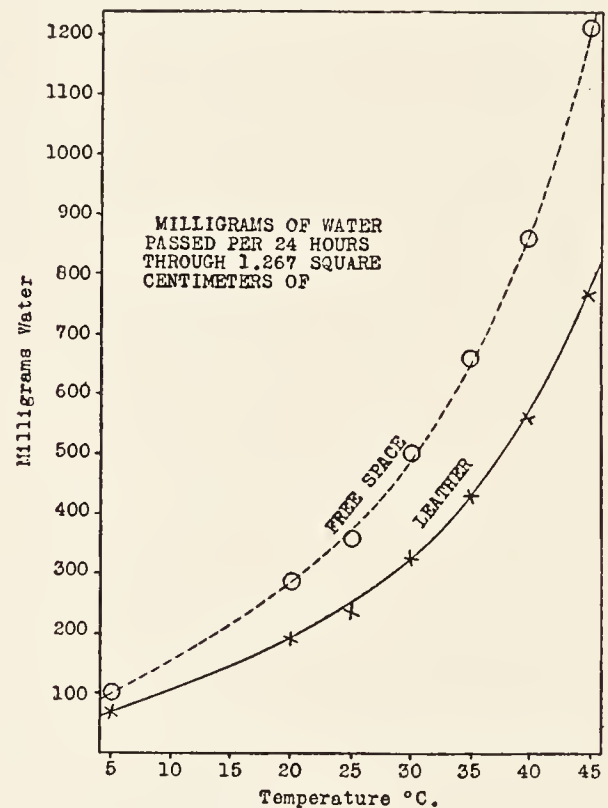


FIG. 6.—Effect of temperature upon passage of water from an atmosphere of 100 % relative humidity to one of zero relative humidity through vegetable-tanned calf leather and through free space (\*).

Relative resilience is defined as the percentage rebound of a brass plunger (weighing 48.5 g and having a contact area of 0.70 cm<sup>2</sup>) when dropped from a height of 60 cm upon a thickness of 3 mm of leather backed by a solid maple block. Relative humidity 50%.

The relative resilience is decreased by an increasing content of either water or oil.

## RESILIENCE (1, 7)

Ind. No.....	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Rel. resilience.....	22	26	28	24	16	23	21	21	22	21	23	19	22	23	17	11	39	17

## LITERATURE

(For a key to the periodicals see end of volume)

- (1) Wilson *et. al.*, 261, 21: 193, 198, 241; 26. (2) Wilson and Gallun, 45, 16: 268; 24. (3) Wilson, 45, 17: 829; 25. (4) Wilson and Gallun, 45, 16: 1147; 24. (5) Wilson and Kern, 45, 18: 312; 26. (6) Wilson and Lines, 45, 17: 570; 25. (7) Wilson, 261, 20: 576; 25. (8) Wilson and Kern, 261, 21: 250; 26.

## RUBBER, GUTTA-PERCHA AND BALATA

G. STAFFORD WHITBY

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## ABBREVIATIONS

$T_B$	Breaking load expressed unless otherwise stated as kg per cm <sup>2</sup> unstrained cross section
$E_B$	Ultimate elongation (percentage of unstrained length)
$T_x$	Stiffness, expressed as the load (kg/cm <sup>2</sup> unstrained cross section) required to produce an increase in length $x$ times the unstrained length
$E_T$	Stiffness, expressed as the percentage elongation produced by a load $T$ kg/cm <sup>2</sup> unstrained cross section

V. C. Vulcanization coefficient

$D_{30}$  Plasticity expressed as the thickness of a disc (0.4 g) after 30 min in a Williams' plastometer at 100° under a load of 5 kg

$\Delta D$  Plasticity expressed as  $D_{25} - D_{35}$

Cure Unless otherwise indicated, the period of vulcanization required to give an optimum or standard "cure."

$\eta$  Viscosity, expressed unless otherwise indicated as the time of flow of a 1% solution in benzene relative to the time of flow of the pure solvent.



**LATEX**  
**Specific Gravity**

*Average Undiluted Latex.*—0.97 to 0.98 (197).  
*Serum from Normal Latex.*—1.016 to 1.025 (197).  
*Globules in Latex.*—0.914 (181).

TABLE 1.—VARIATION WITH RUBBER CONTENT OF ORIGINAL UNDILUTED LATEX (197)

g rubber/100 cm <sup>3</sup> .....	50	45	40	35	30
$d_4^{20}$ .....	0.9620	0.9678	0.9736	0.9794	0.9852
g rubber/100 cm <sup>3</sup> .....	25	20	17	15	10
$d_4^{20}$ .....	0.9910	0.9968	1.0003	1.0026	1.0084

TABLE 2.—TEMPERATURE COEFFICIENT OF SPECIFIC GRAVITY OF LATEX (81)

Sp. gr. ....	0.9950	0.9900	0.9850	0.9800	0.9750
Corr. 1°.....	0.00030	0.00034	0.00038	0.00042	0.00046

**Viscosity**

TABLE 3.—VISCOSITY OF ORIGINAL LATEX WITH AND WITHOUT NH<sub>3</sub> (191)

% rubber content.....	35	30	25	20	15
$\eta/\eta_w$ at 30°	Without NH <sub>3</sub>	12-15	8	5-6	4
	With NH <sub>3</sub> .....	4-5.5	3-4	2.5	2

\* Viscosity falls on keeping.

TABLE 4.—INFLUENCE OF DILUTION ON VISCOSITY OF AMMONIATED LATEX (94)

Ratio		% solids	$d_4^{20}$	200 cm <sup>3</sup> in Engler viscosimeter	
Latex	Water			Sec	Deg. Engler
5	0	48.5	0.963	110	2.1
4	1	37.5	0.972	75	1.42
2.5	2.5	24.25	0.981	65	1.23
2	3	18.7	0.983	60	1.15
1	4	9.4	0.992	50	1.0

**Surface Tension (10)**

*Drop No.*—(a) water, 31; (b) latex diluted with equal volume of water, 37 to 40; (c) 2% NH<sub>3</sub>, 37 to 38; (d) c after 2 months, 49 to 50.

**Miscellaneous**

*Fresh Latex.*—pH: 5.8 to 6.4 (10), 6.2 to 6.6 (20); acidity: 0.02 to 0.04N (phenolphthalein) (190); alkalinity: 0.002 to 0.008N (methyl red) (190).

*Potential Difference between Surface of Particles and Surrounding Liquid (Ammoniated Latex).*— -35 millivolts (145).

*Size and Shape of Globules* (19, 66, 225).

**Rubber Content**

TABLE 5.—DISTRIBUTION OF RUBBER CONTENT IN LATEX FROM 245 7-YR OLD TREES (211)  
Mean: 36.58  $\pm$  0.25%

g/100 cm <sup>3</sup> .....	23	24-5	26-7	28-9	30-1	32-3	34-5	36-7	
Number of trees.....	4	2	7	11	16	27	44	35	
g/100 cm <sup>3</sup> .....	38-9	40-1	42-3	44-5	46-7	48-9	50-1	52-3	54-5
Number of trees....	23	12	17	12	5	1	4	3	2

Influence of severity of tapping (181) and of resting trees (179, 181) on rubber content of latex; cf. Tables 7, 8.

**Chemical Composition**

*Acetaldehyde in Latex.*—0.006 g/l (91). Trace of NH<sub>3</sub> present (91).

*Heat-Coagulable Protein in Serum.*—After coagulation by acetic acid, 0.15% (rubber content of latex, 40%) (11); 0.115% (203); after coagulation by alcohol, 0.19% (203).

TABLE 6

Component	Sample a(7)	b(7)	c(7)	d(130)	e(71)
Total solids.....	30.0	22.0	25.8	32.4	
Rubber by coagulation.....				29.0	37.0
Solids in serum.....				3.4	2.91
Solids in dialysate.....	2.6	1.65	1.54	3.2	
Protein (non-diffusible, N $\times$ 6.25).....	1.26	0.87	1.04		
Diffusible N:					
Total.....	0.048	0.054	0.043	0.072	
Ammoniacal.....				0.0096	

Total N (mean of 3 samples): 0.29 for f(11).

Dialysates from samples a, b, c (mean values)

	Sugars*	Ash	SO <sub>3</sub>	P <sub>2</sub> O <sub>5</sub>	CaO	MgO	K <sub>2</sub> O
% latex.....	0.18	0.31	0.008	0.09	0.01	0.016	0.17
% ash.....		2.6	29.1	3.2	5.2	54.8	

\* After inversion.

Serum solids from sample e, NH<sub>3</sub> also present

	Ash	Protein (N $\times$ 6.25)	Sugars	Quebrachitol
g/100 cm <sup>3</sup> .....	0.53	0.34	0.25	1.45

**Deposit Which Forms in Ammoniated Latex**

Composition of deposit (ca. 0 to 7% of the latex) (37), %: Of this deposit ca. 30% is volatile in steam in the presence of MgO.

	Sample 3*	Sample 5*
Rubber.....	ca. 30	ca. 30
Acetone extract.....	11.6	6.4
N insol. in Me <sub>2</sub> CO.....	2.4	1.6
Fe <sub>2</sub> O <sub>3</sub> .....	9.0	15.1
MgO.....	16.0	13.1
P <sub>2</sub> O <sub>5</sub> .....	28.0	23.6
K <sub>2</sub> SO <sub>4</sub> .....	Tr.	Tr.

\* See Table 9.

Deposit consisting of NH<sub>4</sub>MgPO<sub>4</sub>, 0.3 to 1.1 g/l (190).

**Oxidases**

*Present.*—Peroxidase (the chief oxidase; fatal temperature, 80 to 85°); oxidase; catalase; tyrosinase (fatal temperature, 70°). Optimum pH, 4.65 to 4.95, using citrate buffer solution; 8.13 to 8.28, using borax buffer solution. Inhibitory pH, 1.03; very sensitive to alkali (21).

*Activators.*—Ca and Mg salts (21, 207).

TABLE 7.—RUBBER CONTENT OF LATEX AND SOLID CONTENT OF SERUM UNDER DIFFERENT TAPPING SYSTEMS (203)

Tapping system	1 cut on $\frac{1}{3}$	2 cuts on $\frac{1}{4}$	2 cuts on $\frac{1}{2}$	2 cuts on $\frac{3}{4}$	2 cuts on $\frac{1}{1}$
Rubber content*.....	34.2	31.65	28.2	22.75	22.4
Solid content†.....	8.8	9.5	10.1	8.6	11.6

\* g/100 cm<sup>3</sup> by coagulation. † Expressed on rubber %.

TABLE 8.—INFLUENCE OF RESTING TREES ON RUBBER CONTENT OF LATEX AND SOLID CONTENT OF SERUM (6)

Days after tapping began following long rest	1	3	12	18	22	33
Rubber content by coagulation (%)	43.0	39.3	31.5	35.8	21.8	14.8
Serum solids (% of rubber).....	4.9	7.1	10.15	13.2	13.8	16.9

**Ammoniated Latex**

0.33% NH<sub>3</sub> will preserve latex in liquid condition, while 0.5%, giving an alkalinity of 0.25N (methyl red), is absolutely reliable (190).

TABLE 9.—COAGULATION OF AMMONIATED LATEX IN EUROPE (37)

Sample	Rubber content, %	NH <sub>3</sub> content (% rubber)		% CH <sub>3</sub> CO <sub>2</sub> H*
		Added (in Ceylon)	Found (In Europe)	
1	33.2	0.89	0.82	4.4
2	33.0	1.19	1.00	4.46
3	32.5	1.80	1.57	8.75
4	31.8	2.40	2.17	12.2
5	32.6	2.92	2.73	15.8

\* Per cent of acetic acid necessary for coagulation in excess of the acid equivalent to the NH<sub>3</sub> present.

TABLE 10.—VULCANIZING PROPERTIES OF RUBBER BY CH<sub>3</sub>CO<sub>2</sub>H COAGULATION FROM LATEX PRESERVED WITH DIFFERENT PROPORTIONS OF NH<sub>3</sub> (37)

Pure gum mixture (ring-shaped test pieces)

Sample, cf. Table 9	Cure, min	<i>T<sub>B</sub></i>	<i>E<sub>B</sub></i>	<i>E<sub>104</sub></i>	Slope
1	115	164	855	777	35
2	130	157	859	781	36
3	126	144	842	786	37
4	125	147	840	771	36
5	125	164	874	784	36

TABLE 11.—INFLUENCE OF AGE OF AMMONIATED LATEX ON VULCANIZING PROPERTIES OF RUBBER (201)

Undiluted latex containing 0.72% NH<sub>3</sub>; coagulated by CH<sub>3</sub>CO<sub>2</sub>H; stock: rubber, 92.5; S, 7.5%; vulcanized at 148°

	Aqueous extract, %	Acetone extract, %	Cure, min	<i>T<sub>B</sub></i>	η		
					Orig.	After 14 mo	Orig. in acid C <sub>6</sub> H <sub>6</sub>
Control.....	0.44	3.0	110	128	31	29	16
Ammoniated:							
Same day.....	0.37	2.9	90	135	31	30	15.5
Next day.....	0.54	3.2	70	143	27	30	17
After 1 mo.....	0.23	3.2	105	143	53	22.5	19
After 3 mo.....	0.22	3.9	100	124	56	28	18

TABLE 12.—AMMONIATED LATEX CREAMED BY CENTRIFUGATION (129)

Stock: rubber, 92.5; S, 7.5; vulcanized for 90 min at 147°; coagulated by CH<sub>3</sub>CO<sub>2</sub>H

	Composition of rubber by evaporation, %						S*
	Rubber	H <sub>2</sub> O	Acetone extract	Ash	Protein	Aqueous extract	
Orig. latex.....	17.6	2.0	2.3	1.0	4.0	3.4	4.7
Cream.....	48.0	0.6	1.8	0.4	1.8	0.4	3.9
Skimmed latex.....	9.7	4.1	2.9	2.0	7.4	13.1	5.2

\* Per cent combined S.

#### Latex with NaOH

0.5 to 1% NaOH will preserve latex in a liquid condition; 1.3% or more causes the separation of a paste or coagulation, the resulting rubber being of poor quality and becoming tacky on keeping (198).

TABLE 13.—INFLUENCE OF AGE OF NaOH LATEX ON RUBBER (CREPE) BY CH<sub>3</sub>CO<sub>2</sub>H COAGULATION (198)

Stock: rubber, 92.5; S, 7.5; vulcanized at 148° (ring-shaped test pieces)

Period after addition	Ash, %	Aqueous extract, %	Acetone extract, %	N, %	Cure, min	<i>T<sub>B</sub></i>	Slope	η
Control*.....	0.40	1.11	2.6	0.55	<35	133	39.5	24.5
Same day.....	0.31	0.37	3.0	0.52	<45	145	40	33
Next day.....	0.29	0.21	3.1	0.43	80	122	36.5	40.5
1.5 mo.....	0.40	0.28	3.7	0.42	60	122	37	36
3.5 mo.....	0.46	0.30	2.9	0.38	50	137	33	31
6 mo.....	0.34	0.38	3.4	0.50	110	132	38.5	33

\* Same day, no NaOH.

TABLE 14.—RUBBER FROM CREAMED NaOH LATEX (198)

Latex containing 1.1% NaOH allowed to stand 2 yr; layers coagulated by CH<sub>3</sub>CO<sub>2</sub>H; crepe; stock: rubber, 92.5; S, 7.5; vulcanized at 148°.

	Cream	2nd layer	3rd layer	4th layer	Residue
% rubber content.....	62.8	50.0	45.8	26.8	4.4
% H <sub>2</sub> O.....	0.67	0.95	1.72	1.66	1.68
% ash.....	0.55	0.58	0.65	0.73	1.22
% N.....	0.09	0.10	0.13	0.18	0.48
Cure, min.....	55	45	>25	35	
<i>T<sub>B</sub></i> .....	130	135	130	120	
Slope.....	34	34	34	34	
η (ordin.).....	13	30	41	48	78
η (acid).....	7	15	17.5	18.5	26
Plasticity:					
<i>D<sub>30</sub></i> .....	0.88	1.15	1.36	1.29	1.16
Δ <i>D</i> .....	0.085	0.11	0.08	0.10	0.11

#### Vulcanization of Latex

TABLE 15.—INFLUENCE OF PERIOD OF VULCANIZATION AND OF CHARACTER OF THE S ON THE COMBINED S (43)

Composition of mixture: 100 cm<sup>3</sup> latex; 50 cm<sup>3</sup> H<sub>2</sub>O; 2 g S (rubber coagulated by acetone). Latex No. 1: rubber, 32.9%; NH<sub>3</sub>, 0.6%. Latex No. 2: rubber, 30.15%; NH<sub>3</sub>, 0.43%. Vulcanizing conditions: rise to 141°, 10 min; blow-off, 20 min.

Time at 141°, min	Combined sulfur, %			
	Latex No. 1	Latex No. 2		
	Flowers	Flowers	Pptd.	Colloidal
0	0.18	0.13	0.23	0.47
20	0.59		0.85	1.56
30		0.46	1.04	1.87
60	0.91	0.55	1.47	2.44
120	1.07			2.64

TABLE 16.—INFLUENCE OF CONCENTRATION OF S (43)

Composition of mixture: 100 cm<sup>3</sup> latex (30.7% rubber; 0.43% NH<sub>3</sub>); 50 cm<sup>3</sup> H<sub>2</sub>O; 1% S (calculated on rubber + S). Vulcanizing conditions: 10 min rise; 30 min at 141°; 20 min at blow-off.

S		Comb. S, %	<i>E<sub>60</sub></i> (films)
g	% on rubber		
1	3.26	0.64	1000
2	6.51	1.02	954
4	13.02	1.42	951
6	19.53	1.65	886

TABLE 17.—VULCANIZATION WITH SODIUM POLYSULFIDE (43)

Composition of mixture: 120 cm<sup>3</sup> latex (32.9% rubber, 0.6% NH<sub>3</sub>); 10 cm<sup>3</sup> sodium polysulfide (21.0% S on pptn.). Vulcanizing conditions: 10 min rise to 141°; 20 min blow-off.

Period at 141°, min.....	0	20	30	60	120
Combined S, %.....	0.31	0.85	1.02	1.42	1.88

#### Coagulation

*Acidity Necessary for Coagulation.*—By addition of acid, pH = 4.3 to 4.8 (10, 20). By addition of acid to ammoniated latex (dialyzed or undialyzed), pH ca. 5.5 (103). For spontaneous coagulation, pH = 4.8 to 5.6 (20).

#### CH<sub>3</sub>CO<sub>2</sub>H, ACETIC ACID

TABLE 18.—PROPORTION OF CH<sub>3</sub>CO<sub>2</sub>H USED IN PLANTATION PRACTICE (189)

Rubber	15%		25%	
For coagulation on.....	Same day	Next day	Same day	Next day
CH <sub>3</sub> CO <sub>2</sub> H(g/l).....	1-1.25	0.75	1.5	1



TABLE 19.—CONCENTRATION OF  $\text{CH}_3\text{CO}_2\text{H}$  REQUIRED TO COAGULATE LATEX DILUTED TO DIFFERENT EXTENTS (189), cf. (188)

% rubber content	Ratio, acid:rubber	% rubber content	Ratio, acid:rubber
30	1:303	6	1:83.5
24	1:190	3	1:91
18	1:115	1.5	1:125
15	1:100	0.75	1:83.5
12	1:89		

Influence of excess  $\text{CH}_3\text{CO}_2\text{H}$  on properties of crepe: Double the minimum quantity increases time of cure 0 to 5 min; decreases viscosity 0 to 4. Four times minimum quantity increases time of cure 5 to 10 min for the stock: rubber, 92.5; S, 7.5, at  $148^\circ$ ; decreases viscosity 2 to 7 (176).

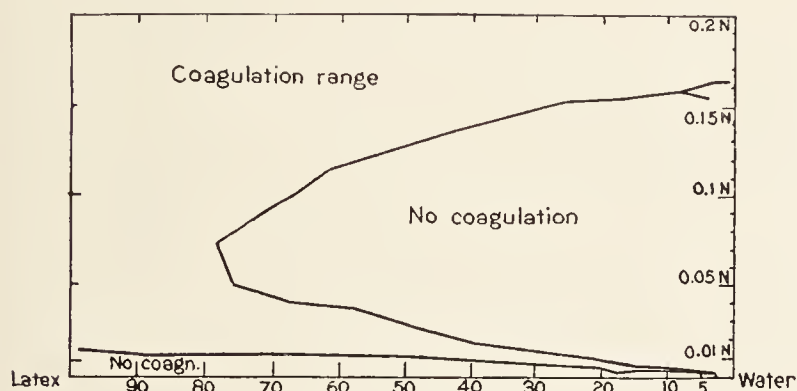


FIG. 1.—Concentrations of hydrochloric acid producing coagulation in latex (31.8% rubber, ca. 35% total solids) diluted to different extents (188).

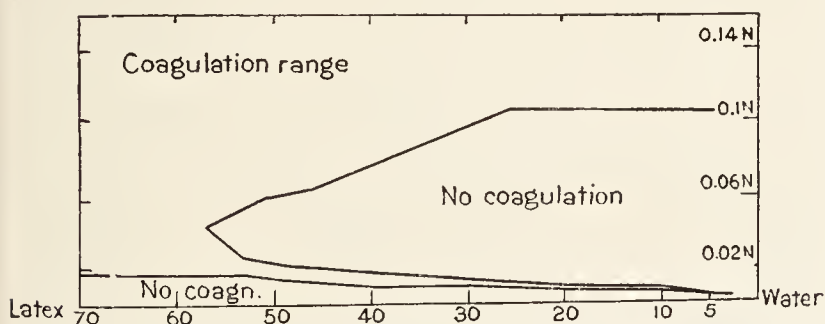


FIG. 2.—Concentrations of nitric acid producing coagulation in latex (28% rubber) diluted to different extents (188).

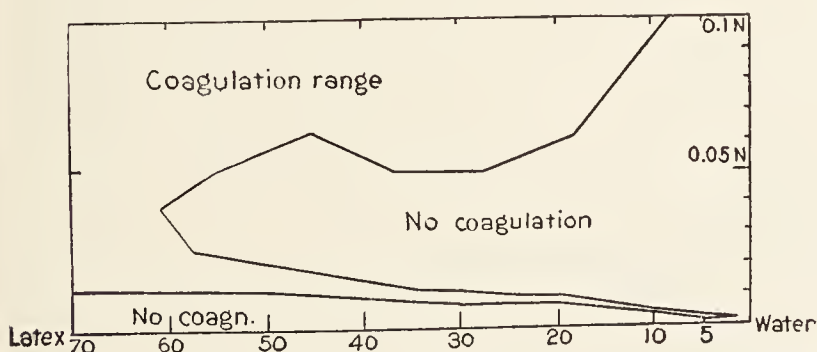


FIG. 3.—Concentrations of sulfuric acid producing coagulation in latex (28% rubber) diluted to different extents (188).

#### $\text{H}_2\text{SO}_4$ , SULFURIC ACID

Proportion  $\text{H}_2\text{SO}_4$  Used in Practice.—0.45 to 0.6 g/l latex (15% rubber).

TABLE 20.—VULCANIZING PROPERTIES OF CREPE RUBBER PREPARED BY  $\text{H}_2\text{SO}_4$  (182)

Stock: rubber, 92.5; S, 7.5; vulcanized at  $148^\circ$  (ring-shaped test pieces)

Normal proportion				Double the normal proportion			
Cure, min	$T_B$	Slope	$\eta$	Cure, min	$T_B$	Slope	$\eta$
125	140	38	35	150	136	38.5	27

#### ALUM

Minimum Effective Proportions.—3 to 4 g/l.

TABLE 21.—EFFECT OF ALUM (COMPARED WITH  $\text{CH}_3\text{CO}_2\text{H}$ ) ON PROPERTIES OF CREPE (182)

Alum (g/l).....	3-4	10	20
Increase in time of cure, min.....	$\leq 15$	$\leq 30$	$\leq 85$
Decrease in viscosity.....	4-7	7-12	10-12

#### $\text{HCO}_2\text{H}$ , FORMIC ACID

The proportion of  $\text{HCO}_2\text{H}$  necessary for coagulation is about half the quantity of  $\text{CH}_3\text{CO}_2\text{H}$  (130); cf. Tables 18, 19.

TABLE 22.—COMPARISON OF  $\text{HCO}_2\text{H}$  AND  $\text{CH}_3\text{CO}_2\text{H}$  (101)  
Stock: rubber, 92.5; S, 7.5%; vulcanized at  $150^\circ$  (ring-shaped test pieces, 11 samples)

Description	Cure, min	$T_B$	Slope	$\eta$
Smoked sheet:				
$\text{CH}_3\text{CO}_2\text{H}$ .....	105	143	36.7	31
$\text{HCO}_2\text{H}$ .....	109	141.5	36.7	35.5
Pale crepe:				
$\text{CH}_3\text{CO}_2\text{H}$ .....	110	143.5	35.6	33
$\text{HCO}_2\text{H}$ .....	113	143	35.5	33

Stock: rubber, 100; S, 3;  $\text{ZnO}$ , 30;  $(\text{CH}_2)_6\text{N}_4$ , hexamethylene-tetramine, 1; vulcanized at  $150^\circ$  (ring-shaped test pieces)

Vulcanization time in min	$T_B$	$E_B$	$E_{130}$	$T_B$	$E_B$	$E_{130}$
Smoked sheet, $\text{CH}_3\text{CO}_2\text{H}$			Smoked sheet, $\text{HCO}_2\text{H}$			
40	185	784	693	173	784	714
50	173	751	678	173	766	695
60	176	763	688	174	769	693
70	146	738	712	167	763	698
80	146	772	748	131	764	762
Pale crepe, $\text{CH}_3\text{CO}_2\text{H}$			Pale crepe, $\text{HCO}_2\text{H}$			
40	165	803	750	168	811	752
50	182	785	712	179	776	708
60	176	778	714	179	782	714
70	167	765	714	168	771	717
80	157	779	738	151	776	743

Stock: rubber, 100; S, 5;  $\text{PbO}$ , 10; vulcanized at  $150^\circ$  (ring-shaped test pieces)

Vulcanization time in min	$T_B$	$E_B$	$E_{100}$	$T_B$	$E_B$	$E_{100}$
Smoked sheet, $\text{CH}_3\text{CO}_2\text{H}$			Smoked sheet, $\text{HCO}_2\text{H}$			
30	106	895	883	102	905	900
60	106	944	932	100	935	935
90	97	989	997	87	977	1000
120	79	1000	1056	84	1014	1060
Pale crepe, $\text{CH}_3\text{CO}_2\text{H}$			Pale crepe, $\text{HCO}_2\text{H}$			
30	125	931	887	118	923	891
60	124	977	933	119	964	929
90	105	1014	1003	105	1006	995
120	94	1027	1042	99	1039	1040

TABLE 23.—CHEMICAL COMPOSITION, %

	H <sub>2</sub> O	Ash	Water extract	Acetone extract	N
Smoked sheet, CH <sub>3</sub> CO <sub>2</sub> H	0.75	0.35	0.75	3.4	0.49
Smoked sheet, HCO <sub>2</sub> H	0.72	0.30	0.58	3.4	0.47
Pale crepe, CH <sub>3</sub> CO <sub>2</sub> H...	0.33	0.23	0.16	3.0	0.36
Pale crepe, HCO <sub>2</sub> H.....	0.37	0.17	0.21	3.0	0.36

TABLE 24.—AGING  
Raw crepe rubber

	Cure, min	<i>T<sub>B</sub></i>	Slope	$\eta$		Plasticity	
				C <sub>6</sub> H <sub>6</sub>	HCl + C <sub>6</sub> H <sub>6</sub>	<i>D</i> <sub>30</sub>	$\Delta D$
Initial, CH <sub>3</sub> CO <sub>2</sub> H	110	141	34	32	17	1.52	0.065
Initial, HCO <sub>2</sub> H...	<120	134	35	31	16.5	1.41	0.07
After 1 yr, CH <sub>3</sub> CO <sub>2</sub> H.....	120	141	35	27	16.5	1.58	0.07
After 1 yr, HCO <sub>2</sub> H	>120	145	35	26	16.5	1.58	0.06

## CHEMICAL COMPOSITION OF RAW RUBBER

TABLE 25.—COMPOSITION OF HEVEA RUBBERS

	Number of samples	H <sub>2</sub> O, %		Ash, %		Acetone extract, %		Protein, % (N $\times$ 6.25)		Water extract, %	Lit.
		Mean	Limits	Mean	Limits	Mean	Limits	Mean	Limits		
Latex crepe.....	102	0.61	0.30-1.08	0.30	0.15-0.87	2.88	2.26-3.45	2.82	2.17-3.76		(130)
Smoked sheet.....	35	0.42	0.18-0.90	0.38	0.25-0.85	2.89	1.52-3.50	2.82	2.18-3.50		(130)
Unsmoked sheet.....	25	0.58	0.32-1.30*	0.23	0.15-0.31	2.88	2.30-3.47	2.31	2.04-2.68		(35)
Fine hard Para.....				0.3		3		2.3		0.5	(183)
Latex sprayed.....	{	1.2	2.5-4.5	1.10	1.6-2.2	4.25		4.2		6.50	(86)
				1.5		4.7		4.2		7.1	(158)
				1.5		5.1		4.3		7.7	(128)
Kerbosch rubber.....	{	4.2				2.2		5.0		1.5	(194)
						2.5		4.5		4.1	(128)

\* % loss on washing.

TABLE 26.—MOISTURE CONTENT OF RAW RUBBER

	Number of samples	Moisture content, %	
		Mean	Limits
In the tropics (177)			
Latex crepe.....	54	0.67	0.34-1.01
Smoked sheet.....	96	0.76	0.43-1.16
Lump crepe.....	17	1.05	0.65-1.80
Scum or skimmings crepe.....	3	0.43	0.35-0.53
Washings crepe.....	6	0.55	0.27-0.78
Scrap crepe.....	15	1.16	0.68-1.64
Dark crepe.....	3	1.07	0.90-1.33
Earth crepe.....	2	0.70	0.60-0.81
In Europe (130)			
Latex crepe.....	102	0.42	0.18-0.90
Smoked sheet.....	35	0.61	0.30-1.08
Fine hard Para, washed and air-dried.....			0.56
Caucho.....			0.31

TABLE 27.—RESIN CONTENT

*Hevea*.—v. Table 29.*Castilloa*, %.—16.7, 18.9 (130); 5.4-52 (17 samples) (26).*Ceara (Manicoba)*, %.—3.4, 6.8 (130); 2.0 (206).*Congo*, %.—2.0, 4.4, 5.2 (130).*Kassai, Red*.—3.8 (206).*Kassai, Black*.—4.0 (206).*Jelutong*.—76-81 (3 samples) (55).

TABLE 24.—AGING.—(Continued)

Vulcanized rubber; stock: rubber, 92.5; S, 7.5; vulcanized at 150° (ring-shaped test pieces)

Cure, min	<i>T<sub>B</sub></i>		Change in <i>E</i> <sub>130</sub>
	Initial	After 1 yr	
75, CH <sub>3</sub> CO <sub>2</sub> H.....	86	119	ca. 170
75, HCO <sub>2</sub> H.....	86	118	ca. 170
120, CH <sub>3</sub> CO <sub>2</sub> H.....	133	17	
120, HCO <sub>2</sub> H.....	140	16	

## OTHER COAGULANTS

Hydrofluoric (57), citric (57), oxalic (57), tartaric (57), lactic (202), sulfurous acids (178); calcium chloride (208); alcohol (40); pyroligneous acid (58); freezing (58); electrolysis (187).

TABLE 28.—OPTICAL ACTIVITY OF RESIN FROM VARIOUS RUBBERS (85)

Source	$[\alpha]_D^{20}$	Source	$[\alpha]_D^{20}$
Upper Congo.....	12-13°	Padang.....	28-30°
Manaos.....	16-18°	Guayule.....	11-15°
Peruvian.....	29-31°	Kassai.....	29-30°
Jelutong.....	49-50°		

TABLE 29.—SAPONIFIABILITY (130)

Rubber	Resin, %	Unsaponifiable, %	
		Of the rubber	Of the resin
Fine hard Para.....	3.0	0.8	25.4
Hevea sheet.....	1.8	0.9	48.3
Hevea crepe.....	3.2	0.7	22.0
Castilloa.....	18.9	14.0	73.7
Congo.....	4.4	3.0	68.3
Jelutong.....	38.1	31.7	83.2
Jelutong crepe.....	7.2	5.6	77.8

TABLE 30.—NITROGENOUS CONSTITUENTS

Average N content of crepe and sheet, 0.45%; of slab, 0.21-0.30% (57).

A sample of crepe contained 0.40% N, representing 61.5% of the total N (0.11%) of the latex (57).

*Properties of Rubber Proteins*.—v. (11, 12, 150).

*Nitrogen in Acetone Extract*.—Crepe (2 samples), 0.04; sheet, 0.014; fine hard Para, 0.053; Manicoba, 0.069; Manihot, 0.041; Castilloa, 0.027; hard Congo, 0.013; soft Congo, 0.15% (130)



TABLE 31.—CONSTITUENTS IDENTIFIED IN THE RESIN OF HEVEA RUBBER

Constituent	M. P., °C	$[\alpha]_D^{25}$	Approximate % of the raw rubber
Smoked sheet and latex crepe (215)*			
Phytosterol ester.....	83	-11.0° (24°)	0.075
Sitosterol <i>d</i> -glucoside..	285-90 d	-41.7° (23°)	0.175
Phytosterol.....	125	-24.6° (23.5°)	0.225
<i>d</i> -Valine.....	ca. 260 d	26.5° (16°)	0.015
Quebrachitol.....	190	-80.3° (20°)	Tr.
Stearic acid.....			0.15
Oleic + linoleic acids..			1.25

\* In slab (matured) rubber (28) acetic and valeric acids have been identified (probably as the  $\text{NH}_4$  salt or amide); also valeramide, M. P. 102-3°, and palmitic and stearic acids (0.5-0.7 %).

TABLE 32.—ACID CONTENT  
Water-soluble acids\* by cold extraction for 24 hr (130)

Sheet				Crepe			
Number of samples	Mean	Maximum	Minimum	Number of samples	Mean	Maximum	Minimum
35	0.03	0.078	0.006	102	0.006	0.024	0.006

\* Results expressed as % acetic acid.

By extraction with boiling water (8, 50, 136). Pale crepe, 0-0.1%; smoked sheet, 0.055-0.25%.

Acetone-soluble acids

Kind of rubber	a (213, 214, 222)				b (28)			
	Number of samples	Acid number*			Number of samples	Acid number*		
		Mean	Maximum	Minimum		Mean	Maximum	Minimum
Hevea smoked sheet..	19	275	314	234		292	300	284
Hevea latex crepe....	12	282	296	272				
Fine hard Para.....	12	218	384	100		215		
Hevea scrap (brown) crepe.....	3	151	223	92				
Latex sprayed.....	3	453	534	301	2	273.5		
Slab (matured rubber):								
Unwashed.....					3	851	896	818
Outside.....	1	256						
Interior.....	1	459						
Washed.....	1	224			2	237.5	240	235
Palembang "plain sheet".....					3		366	336
Caucho.....	1	57						
Kassai.....	1	75						
Massai.....					2	182	182	166

c (34). Acid number: Fine hard Para, 294; Kassai, 32; Guayule, 240; Ceara, 172; Upper Congo, 43; Benguella, 60; Peruvian, 18; Accra lumps, 75.5.

\* Acid number = mg KOH required to neutralize the acid in the acetone or alcohol extract from 100 g rubber.

TABLE 33.—MANGANESE CONTENT (29)

	Number of samples	g Mn/100 kg	
		Mean	Limits
Sound rubber (fine hard Para, sheet, crepe, slab).....	11	0.16	0.125-0.625
Very tacky rubber (sheet, brown crepe).....	5	20.0	

## PHYSICAL PROPERTIES OF RAW RUBBER

Coefficient of cubical expansion: under no load,  $\frac{10^6 dV}{V dt} =$  at 10°, 657; 20°, 665; 30°, 670 (133). At constant length practically the same values hold as those for no load (99, 105, 133).

TABLE 34

	$d_4^{20}$	$V_M^{20}$	$n_D^{20}$	$M_D$
Purified rubber (106).....	0.9237		1.5219 <sup>20</sup>	22.46
Smoked sheet (106).....	0.9217	73.8	1.5208 <sup>20</sup>	22.44
Pale crepe (164), cf. (42).....			1.525 <sup>15</sup>	
Synthetic methyl rubber (106)	0.9292	88.23	1.525 <sup>20</sup>	27.03

## Viscosity of Raw Rubber and Its Solutions

## RUBBER

TABLE 34A

Unmilled.—ca. 10<sup>20</sup> poise at 15.5° (1). (By extrapolation from values for solutions.)

Milled (77).

Period of milling, min.....	10	22	32	39
10 <sup>-7</sup> $\eta$ at 100°.....	9.3	5.0	3.2	2.4

Heavily Milled.— $\eta = 22.4 \times 10^5$  at 10°;  $2.29 \times 10^5$  at 60° (1).

## UNMILLED RUBBER SOLUTIONS

Ostwald viscosimeter used unless otherwise indicated

TABLE 35.—CASTILLOA RUBBER (65)

Number of samples	Resin content, %	Relative viscosity in benzene					
		0.25 %		0.5 %		1.0 %	
		Mean	Limits	Mean	Limits	Mean	Limits
13	18.9-37.0	3.0	2.0-3.5	6.7	3.5-9.0	26.0	9.2-36.5

For viscosity of 1 % solution in benzene of typical samples of Hevea rubber v. Tables 49, 57, 58.

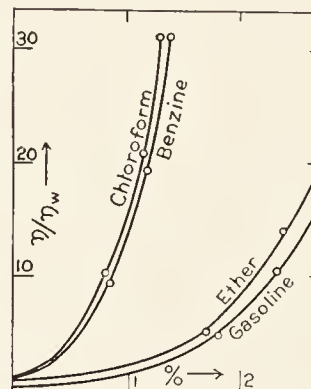


FIG. 4.—Viscosity of plantation rubber in various solvents (67).

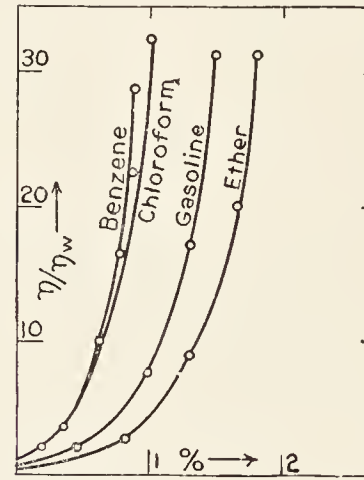


FIG. 5.—Viscosity of fine hard Para rubber in various solvents (67).

TABLE 36.—CONCENTRATED SOLUTIONS IN BENZENE (1)  
Falling sphere method

Concentration, %.....	2	3	4	5	6
$\eta$ at 15°, poise.....	5.04	35.63	162.8	464.4	1577

TABLE 37.—ONE PER CENT SOLUTION IN CHLOROFORM (113)

	Number of samples	$\eta/\eta_0$ at 25°, centipoise	
		Mean	Limits
Pale crepe.....	5	32.7	22.5-41.6
Smoked sheet.....	12	22.9	16.3-26.6

TABLE 38.—COMPARISON OF VISCOSITY IN  $C_6H_6$ ,  $C_7H_8$  AND  $CCl_4$  (130)

Extreme samples in a series of 5 samples						
Solvent	Sample No. 1			Sample No. 5		
	$C_6H_6$	$C_7H_8$	$CCl_4$	$C_6H_6$	$C_7H_8$	$CCl_4$
Conen .....	0.998	0.998	0.997	0.993	0.991	0.993
$\eta/\eta_0$ .....	20.26	20.94	29.95	53.5	68.1	119.5
$\eta/\eta_{C_6H_6 \text{ soln.}}$ .....	1.00	1.04	1.48		1.29	2.24

TABLE 39.—VISCOSITY IN VARIOUS SOLVENTS AT VARIOUS CONCENTRATIONS (92)

Solvent	g/100 cm <sup>3</sup> solvent	0.5	1	2	3
Benzine.....		1.9	4.3		94.0
Benzene.....		2.1	4.7	23.5	97.3
Carbon tetrachloride.....		2.6	7.5		211.3
Tetrachloroethane.....		2.5	6.9		168
Pentachloroethane.....		3.0	8.7	46.0	213.5

Variations of viscosity with concentration: (1)  $\eta_x = k^x$ , where  $\eta_x$  = the viscosity at concentration  $x$ ;  $k$  = a constant (67). (2)  $\log \eta/\eta_0 = \theta C$ , where  $\eta$  = viscosity of solution,  $\eta_0$  = viscosity of solvent,  $C$  = concentration (147).

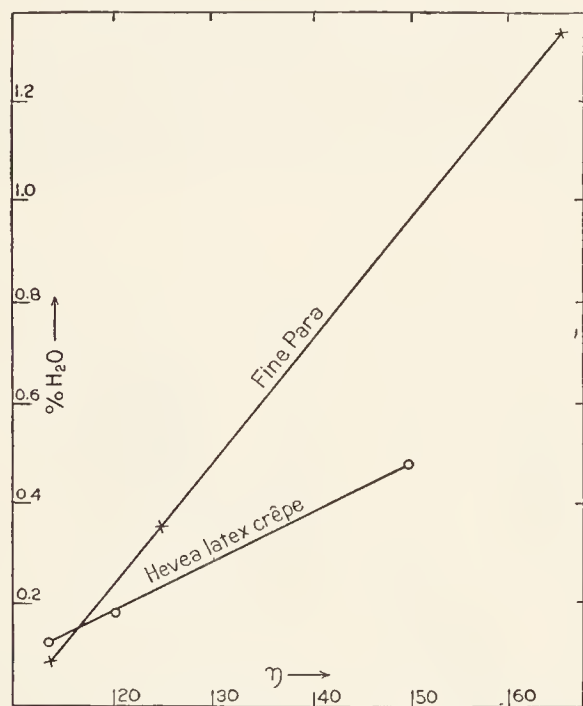


FIG. 6.—Influence of water on viscosity of benzene solutions (92).

TABLE 40.—INFLUENCE OF HEATING ON VISCOSITY (67)  
Toluene solution at 40°

Period of heating, days.....	0	6	12
Time of efflux, sec.....	260	150	129

Xylene solutions at 80°

Period of heating	g/100 cm <sup>3</sup>	Time of efflux, sec					
		0.4	0.48	0.54	0.60	0.73	0.82
0.....		61.5	73.0	87.0	104.5	138.0	187.0
30 min.....		53.0	62.0	74.0	89.5	120.0	161.0
1 hr.....		51.0	60.0	70.0	81.5	111.5	148.0
2 hr.....		46.5	57.0	64.0	73.5	105.0	132.0
3 hr.....		44.0	56.0	62.0	69.0	98.0	124.5

Xylene solutions heated 2 hr at 100°

Rubber	Number of samples	Time of efflux, sec	
		Initial	After heating
Fine hard Para.....	3	111–103	48–46
Plantation Hevea.....	3	115–108	72–65
Fine hard Para (45 min in cold)...	1	118	81
Funtumia.....	3	104–100	81–70
Castilloa.....	2	111, 107	80.5, 78
Ceara.....	1	118	90

Law of diminution of viscosity with time of heating:  $x = a + b \log t$ , where  $x$  = diminution in time  $t$ ;  $a$  = diminution in first unit of time;  $b$  = increment of diminution with time (67).

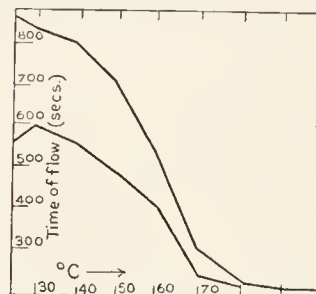


FIG. 7.—Viscosities at 18° of 0.5% solutions in xylene of two samples of plantation rubber heated for two hours at various temperatures (13).

TABLE 41.—INFLUENCE OF ULTRA-VIOLET LIGHT\* (13)

	Plantation					Fine Para				
Min exposed.....	0	15	30	45	60	0	15	30	45	60
Viscosity†.....	90	57	30	25	15	180	109	32	25	15

\* Three per cent solution in xylene exposed at distance of 12 cm from quartz lamp (110 volts, 2.5 amp.).

† Frank-Mackwald viscosimeter.

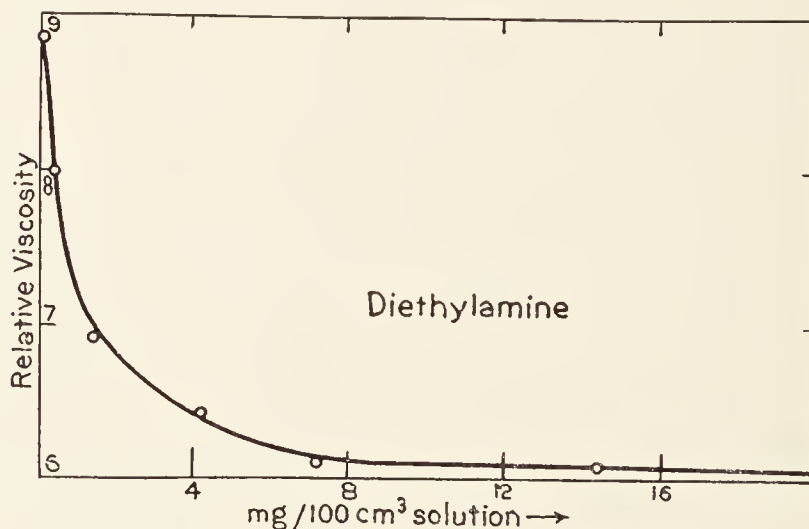


FIG. 8.—Influence of diethylamine on the viscosity of a benzene solution of rubber (218).

## MILLED RUBBER SOLUTIONS

TABLE 42.—INFLUENCE OF MILLING. 2% SOLUTION  
IN  $C_6H_6$  (13)

Milling period, min.....	25	5	10	15	20	30	40	50	60
Time of flow, sec.....	1900	540	150	100	90	70	65	60	59

TABLE 43.—EFFECT OF TEMPERATURE ON VISCOSITY AND DENSITY  
Falling sphere method; heavily milled smoked sheet (10 g/100 cm<sup>3</sup> solution in  $C_6H_6$ ) (1)

°C	11.3	14.6	20.0	30.0	42.0	50.0	62.0
$d_4^t$	0.890	0.887	0.881	0.871	0.859	0.851	0.840
$\eta^*$	3.97	3.77	3.42	2.92	2.57	2.32	1.95

\* Expressed in poises.



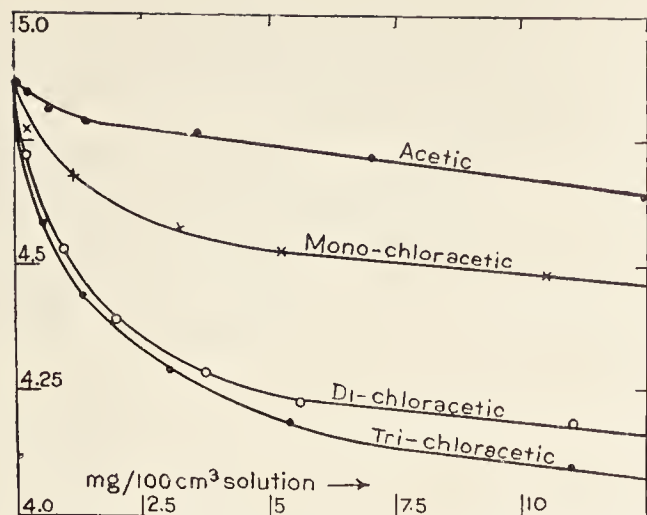


FIG. 9.—Influence of acetic and the chloroacetic acids on the viscosity of a benzene solution of resin-free rubber (<sup>218</sup>); cf. (60, 150, 192).

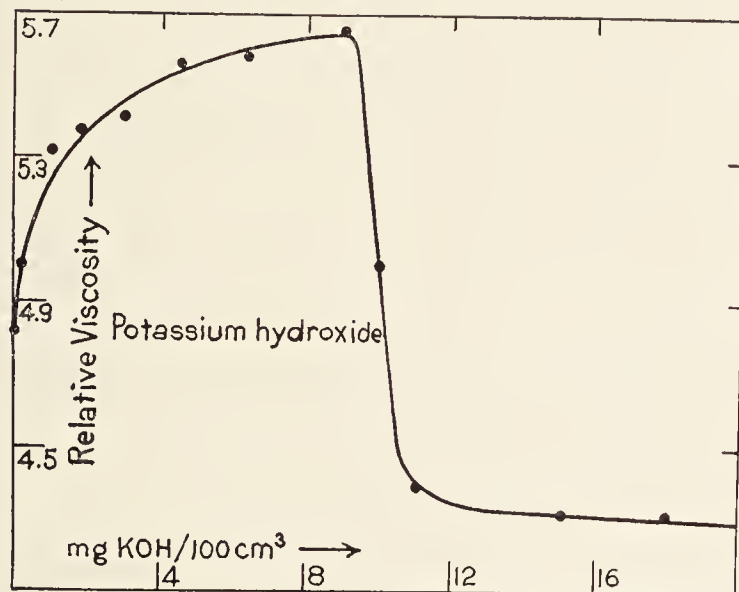


FIG. 10.—Influence of KOH on the viscosity of a benzene solution of a resin-free rubber (0.4961 g per 100 cm<sup>3</sup>) (<sup>218</sup>).

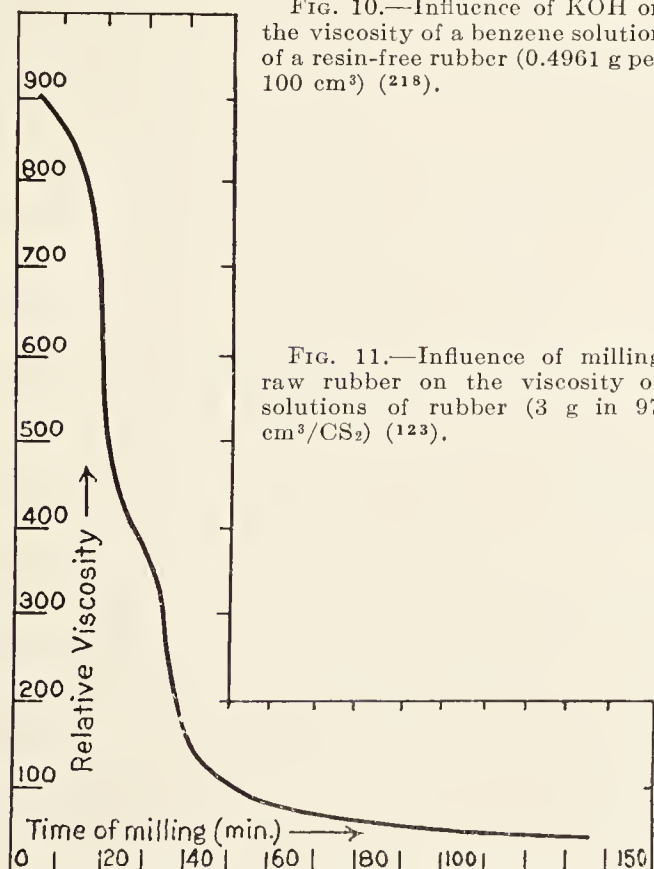


FIG. 11.—Influence of milling raw rubber on the viscosity of solutions of rubber (3 g in 97 cm<sup>3</sup>/CS<sub>2</sub>) (<sup>123</sup>).

TABLE 44—VISCOSITY OF BENZENE SOLUTIONS OF HEAVILY MILLED RUBBER AT LOW CONCENTRATIONS (<sup>1</sup>)

Same sample as in Table 43 and Fig. 12

Concn.....	0	0.5	1.0	2.0	3.0
$\eta$ , poises.....	0.0063	0.0124	0.021	0.055	0.131

Relation between viscosity and concentration (<sup>1</sup>):  $\eta_c = K e^{k\sqrt{c}}$ , for  $c = 1 - 40$ , where  $c = \text{concn.}$ ;  $K$  and  $k$  are constants;  $e =$  base Napierian logs.

TABLE 45.—INFLUENCE OF LIGHT (<sup>123</sup>)

Solutions of milled rubber in benzene exposed to light through a screen of benzene: (a) 3 g/97 cm<sup>3</sup> benzene. (b) a + 0.06 g Sudan III/100 cm<sup>3</sup>.

	(a) exposed	(b) exposed	(b) protected
Initial viscosity....	548.7	548.7	548.7
After 30 days.....	52.5	457.0	473.2
After 60 days.....	30.2	339.0	393.2

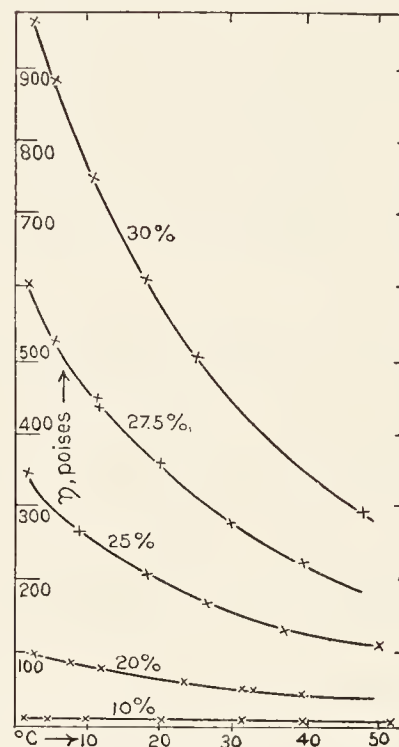


FIG. 12.—Viscosity of rubber solutions in C<sub>6</sub>H<sub>6</sub>; variation with temperature and concentration (falling sphere method) (<sup>1</sup>).

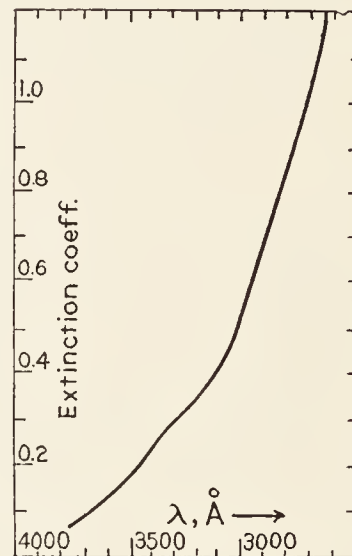


FIG. 13.—Ultra-violet absorption spectrum curve of ether solution of caoutchouc calculated on a 3% solution in a 1 cm cell (<sup>102</sup>).

### Tensile Properties

TABLE 46

At room temperature: unmilled sheet (16 samples from a single sheet),  $T_B$ : 10.4 (limits: 7.8–18.1);  $E_B$ : 527 (limits: 423–616) (<sup>130</sup>).

At low temperature: rubber calendered and then allowed to age before testing (cross section of test pieces not stated) (<sup>101</sup>).

	Crepe					Fine hard Para			
°C .....	-13	-21	-34	-50	-55	-13	-23	-37	-51
$E_5$ .....	425	320	275	120	50			290	250
Breaking load, kg .	8	20	40	40	20	3	4	40	20
$E_B$ .....	530	610	670	710	570	360	280	650	705
	Fine weak Para					Congo			
°C .....	-14	-23	-40	-53		-15	-26	-42	-55
$E_5$ .....	510	460	440	120			520	440	20
Breaking load, kg .	5	20	30	16		2	5	25	20
$E_B$ .....	510	700	790	610		500	520	850	640

TABLE 46.—(Continued)

At optimum temperature;  $E$  (%) for (a) crepe and (b) fine hard Para (101)

Load, kg. ....	1	2	3	4	5	6	7	8	9
(a) at $-34^\circ$ .....	0	0	50	200	275	320	370	400	430
(b) at $-37^\circ$ .....	0	10	110	220	290	350	400	440	460
Load, kg. ....	10	12	14	16	18	20	25	30	40
(a) at $-34^\circ$ .....	460	490	510	540	560	580	610	640	670
(b) at $-37^\circ$ .....	470	490	520	540	560	570	610	630	650

## VARIOUS TYPES OF HEVEA

Vulcanizing Properties, Etc., of Various Types and Grades of Hevea Rubber

## LATEX CREPE AND SMOKED SHEET

TABLE 47

Stock: rubber, 92.5; S, 7.5; vulcanized at  $150^\circ$  (ring-shaped test pieces)

Type of rubber	Number of samples	Cure, min	$T_B$	Slope	$\eta/\eta_0$ §	Lit.
Pale crepe*....	1293	108.7 ± 7.6	142.4	35.4	33.5	(195)
Smoked sheet*.	853	105.9 ± 12.5	143.5	36.7	33.9	(195)
Pale crepe*†...	101	109.2 ± 7.2	140.8	36.0	34.7	(195)
Smoked sheet*†	149	104.6 ± 11.7	142.7	37.9	33.5	(195)
Pale crepe‡....	1668	110.5	140.3	35.2	32.3	(192)
Smoked sheet‡.	1647	97.5	140.7	36.4	32.6	(192)

\* Prepared 1921–23. † Ca. 100 plantations sampled. ‡ Prepared 1917–23. § One per cent in  $C_6H_6$ .

## Distribution as regards time of cure (195)

Type of rubber	Number of samples	Variation from medium value, %		
		< 10	< 20	> 20
Pale crepe.....	1293	83.5	99.5	0.5
Smoked sheet.....	853	60.5	91	9
Pale crepe.....	101	86	99	1
Smoked sheet.....	149	64.5	90	10

Stock: rubber, 90; S, 10; vulcanized at  $140^\circ$ . Mean for latex crepe: (cure = 195 min)  $T_B = 130$ . Mean for smoked sheet: (cure = 165 min)  $T_B = 146$  (57).

TABLE 48.—VULCANIZATION COEFFICIENTS (110)

Data refer to a "standard" cure, i.e.  $T_{80} = 136$  in the stock: rubber, 90; S, 10; vulcanized at  $148^\circ$

Age of tree	10 year old trees*		20 year old trees*	
	Cure, min	V. C.	Cure, min	V. C.
Latex crepe.....	107	5.20 ± 0.16	126	5.00 ± 0.07
Sheet .....	61	5.47 ± 0.19	72	5.38 ± 0.10

\* Six samples.

## FINE HARD PARA

Mean Values.—Rubber, 92.5; S, 7.5; vulcanized at  $150^\circ$ . (Ring-shaped test pieces.) Cure (min), 100;  $T_B$ , 145; slope, 35.39;  $\eta$ , (1% in  $C_6H_6$ ), 33 (182).

TABLE 50.—COMPARISON WITH SMOKED SHEET FROM SAME LATEX (209)

Stock: rubber, 90; S, 10; vulcanized at  $141^\circ$  (ring-shaped test pieces)

Type	Cure, hr	$T_B$	$E_B$	Slope
Brazilian from young trees...	2.25	168	929	40
Smoked sheet from young trees.....	1.75	158.5	928	38
Brazilian from old trees.....	2.25	153	919	38
Smoked sheet from old trees.	2.25	149.5	944	36

## CEYLON BLANKET CREPE

TABLE 49 (154)

Stock: rubber, 92.5; S, 7.5; vulcanized at  $150^\circ$  (ring-shaped test pieces)

	Air dried mean*	Heat dried mean†	Average (17 samples)		Thin crepe (for comparison)	
			Mean	Limits	Mean	Limits
Thickness, mm...			11	4–22		
Moisture, %....			0.4	0.24–0.62	0.6	0.35–1.0
Ash, %.....			0.2	0.12–0.33		
Vulcanization time in min....	124	132	129	115–140	109	
$T_B$ .....	146	140	142		142	
Slope.....	34	35.5	35	34–36	35.5	
$\eta$ , 1% in $C_6H_6$ ‡...	37	23	29	21–44	34	
$\eta$ , 1% in acid $C_6H_6$ ‡.....	20	15	17	14.5–21.5		

\* 6 samples. † 9 samples. ‡ Rate of flow compared with rate of flow of the solvent.

## SLAB (MATURED RUBBER)

TABLE 51 (205)

Stock: rubber, 92.5; S, 7.5; vulcanized at  $150^\circ$  (ring-shaped test pieces)

Thickness	Number of samples	% loss on washing	Cure, min	$T_B$	Slope
3 cm	11	22.0	35	155	32.2
1–1.5 cm	4	21.6	36	157	31.5

For stock: rubber, 90; S, 10; vulcanized at  $141^\circ$  (ring-shaped test pieces); cure, 75 min;  $T_B = 151$  (mean values) (57).

TABLE 52.—VARIATION IN TIME OF CURE (COMPARED WITH CREPE AND SHEET) (205)

Stock: rubber, 92.5; S, 7.5; vulcanized at  $150^\circ$

Type	Cure, min		% deviation	
	Mean	Limits	Maximum	Mean
Slab (193 samples)*.....	35.5	15–57	118	18.8
1920–1924 samples of:				
Pale crepe.....	108.2	80–135	51	6.66
Smoked sheet.....	103.9	65–150	78	11.62

\* By  $CH_3CO_2H$  and natural coagulation.

## LATEX SPRAYED RUBBER

Comparison with sheet and crepe

TABLE 53 (86)

Stock: rubber, 100; S, 10; at  $141^\circ$

Type	Number of samples	Cure, min	$T_B$
Latex sprayed.....	20	127	251
Smoked sheet.....	20	165	230
Latex crepe.....	20	183	227

TABLE 54 (38)

Stock: rubber, 90; S, 10; at  $148^\circ$  (ring-shaped test pieces); cure giving load-strain curve passing approx. through  $E_{775} = 104$

Type	Number of samples	Cure, min	$T_B$	$E_B$	Slope
Latex sprayed.....	6	60	157.5	863	39
Smoked sheet.....	5	107	171	867	40
Latex crepe.....	5	136	155.5	854	37



TABLE 55 (38)

Stock: rubber, 90; ZnO, 90; S, 10; hexamethylenetetramine, 1

Type and number of samples	Cure giving					
	Load-strain curve through $E_{480} = 104$			Maximum breaking load		
	Min	$T_B$	$E_B$	Min	$T_B$	$E_B$
Latex sprayed, 3.....	23	184	607	47	193	392
Smoked sheet, 5.....	37	175	604	45	193	458
Latex crepe, 5.....	42	184	624	45	187	478

TABLE 56.—PLASTICITY OF UNMILLED LATEX SPRAYED RUBBER

Number of samples	$D_{30}$	$\Delta D$	$\eta$		Lit.
			1 % in $C_6H_6$	1 % in HCl + $C_6H_6$	
6	1.94	0.08	ca. 40	17	(196)

## OTHER TYPES LATEX RUBBER

*Unsmoked Sheet.*—Differs from smoked sheet only in vulcanizing in about 10 % less time (183).

*Evaporated Latex.*—Time of cure, 70 to 75 % that of crepe (203); 75 min in stock: rubber, 90; S, 10; at 141° (56).

*Kerbosch Rubber.*—Time of cure, 50 to 60 min in stock: rubber, 92.5; S, 7.5; at 150° (194). Deteriorates on aging.

TABLE 57.—LOWER PLANTATION GRADES (183)

Stock: rubber, 92.5; S, 7.5; vulcanized at 150° (ring-shaped test pieces)

	Samples washed crepe	Cure, min		$T_B$		Slope		$\eta$ , 1 % in $C_6H_6$	
		Mean	Limits	Mean	Limits	Mean	Limits	Mean	Limits
Lump (naturally coagulated clots).....	90	104.5	7-130	133	107-150	37.3	33.5-40	30.5	10-58
Scum or skimmings (from tanks, etc.).....	30	112.5	85-135	134	124-142	36.8	34 -40	28.5	20-59
Washings (diluted latex from cups, etc.).....	25	118	95-145	127	106-145	39.1	35.5-46	22.6	15-31
Tree scrap.....	90	105	70-185	125	104-146	38.8	35.5-44.5	25.7	13-48
Bark scrap.....	25	111	90-140	108	82-136	42.9	38 -47.5	19.5	11-33
Earth rubber.....	28	97.5	70-130	126	106-138	37.6	34 -40	20.1	15-28

TABLE 58.—NATIVE RUBBER (155)

Stock: rubber, 92.5; S, 7.5; vulcanized at 150° (ring-shaped test pieces)

	Number of samples	% ash		Cure, min		$T_B$		$\eta$ , 1 % in $C_6H_6$		$\eta$ , 1 % in HC + $C_6H_6$	
		Mean	Limits	Mean	Limits	Mean	Limits	Mean	Limits	Mean	Limits
Crepe prepared in laboratory from native slab*.....	253			96	40-160	138		24.5		12.5	
Amber crepe prepared in native factories†.....	14	1.01	0.2-1.8	114	100-130	130	110-153	20	11-64	11	7-25
Amber crepe prepared from native rubber in Singapore.....	20	0.82	0.5-1.2	93	70-140	140	125-157	20	5-48		
First quality plantation latex crepe (for comparison).....			0.2-0.4	107	80-130	143		33			

\* Per cent washing loss = 10-50 (limits). † Plasticity:  $D_{30} = 1.30$  (mean), 1.0-1.72 (limits);  $\Delta D = 0.07$  (mean), 0.04-0.13 (limits).

## FACTORS IN THE PREPARATION OF HEVEA RUBBER

TABLE 59.—INFLUENCE OF DILUTION OF LATEX ON THE PROPERTIES OF RUBBER (192)

Ring-shaped test pieces

	Cure, min	$T_B$	Slope	$\eta^*$
Undiluted latex				
Crepe milled same day.....	103.5	140	37.2	23.9
Crepe milled next day.....	84.5	142.5	36.7	27.2
Smoked sheet rolled next day.....	69	149	37.8	28.6
Diluted to 15 % rubber content				
Crepe milled same day.....	113.5	138.5	37.7	25.4
Crepe milled next day.....	100.5	140.5	38.0	23.6
Smoked sheet rolled next day.....	80	144.5	37.1	31.0

\* One per cent in  $C_6H_6$ .

TABLE 60.—INFLUENCE OF AGE OF TREES ON PROPERTIES (192)

Ring-shaped test pieces

	Age, yr	Crepe		Sheet	
		Time, min	$T_B$	Time, min	$T_B$
First group of trees.....	3	77	123	59	127
	4.5	82	129	58	134
	7.5	97	138	64	145
Second group of trees.....	4.5	77	125	58	132.5
	8	96	137	68	144.5
Age, yr (184).....	35	19	18	8	
Vulcanization of crepe, min....	145	130	135	110	
$\eta$ , 1 % in $C_6H_6$ .....	50	39	41	28	

TABLE 61.—INFLUENCE OF RESTING TREES (203)

Change in rubber content of latex, vulcanizing properties, viscosity (1% in C<sub>6</sub>H<sub>6</sub>), after a period of rest

Days*	Rubber content, %	Cure, min†				$\eta$			
		Crepe		Sheet		Crepe		Sheet	
		A‡	B§	A‡	B§	A‡	B§	A‡	B§
1-2	51.3	<125	160	115	160	36.5	31.5	42.5	38
3	49.3	125	150	<105	<160	36.5	34	44.5	38.5
7	43.2	125	150	95	145	36.5	30.5	42	37
10	40.9	110	140	<95	125	32	28	40.5	30
14	38.5	<105	130	90	130	31.5	29	33	31
18	35.0	95	130	80	<110	28	23	30.5	25.5
23	32.4	95	<120		100	23	23	32	27.5
28	30.1	<85	115	<80	<100	28	25	29.5	32.5
35	29.0	90	115	75	90	26.5	21.5	32	31.5
39-56	28.4	89	104	69	81	26.9	23.4	30.3	29.5

\* Days after tapping started again. † Stock: rubber, 92.5; S, 7.5; vulcanized at 148°. ‡ A, undiluted latex. § B, latex diluted to 15% rubber content.

TABLE 62.—INFLUENCE OF LENGTH OF REST ON RATE OF CURE (204)

Period of rest, mo. ....	$\frac{1}{2}$	1	2	3	4
Increased time of cure, min* ..	2	10	20	20	40

\* For early tappings (2-6 expts.).

TABLE 63.—INFLUENCE OF ANTICOAGULANTS ON THE PROPERTIES OF RUBBER

	NaHSO <sub>3</sub> *	Na <sub>2</sub> SO <sub>3</sub> ·7H <sub>2</sub> O
Lit. ....	(186)	(186)
g/l latex. ....	0.5-1	2
Increase in $T_B$ ....	0-5	0-5
Decrease in min of cure. ....	5-10	10-15
Decrease in slope. ....	1-1.5	1-1.5
Increase in $\eta$ (1% in C <sub>6</sub> H <sub>6</sub> ) ...	1.5-10	3-10

\* Proportion necessary to inhibit action of latex oxidase: 1 part in 400 to 2400 parts latex (9).

## NON-HEVEA RUBBERS

TABLE 64.—VULCANIZATION OF CAUCHO BALL WITH S ONLY (217)

Stock: rubber, 90; S, 10; vulcanized at 141° (ring-shaped test pieces)

Min	150	180	210	240
$T_8$	6.8	9.2	11.45	
$T_B$	34	46	57	62
$E_B$	1082	1045	1010	968

TABLE 65.—VULCANIZATION OF CAUCHO BALL WITH THE AID OF AN ACCELERATOR (217)

Stock: rubber, 100; S, 5; ZnO, 5; zinc pentamethylenedithiocarbamate, 0.5; vulcanized at 115° (ring-shaped test pieces)

Min	30	60	90	120
$T_7$	53.2	114	120	
$T_B$	130	152	138	27
$E_B$	861	769	737	

TABLE 66.—VULCANIZATION OF FICUS RUBBER WITH S ONLY (217)

Stock: rubber, 90; S, 10; vulcanized at 141° (ring-shaped test pieces)

Min	150	180	210
$T_7$	8.5	11.3	13.6
$T_B$	49	68	83
$E_B$	1112	1102	1074

TABLE 67.—VULCANIZATION OF FICUS RUBBER WITH THE AID OF AN ACCELERATOR (217)

Stock: rubber, 100; S, 5; ZnO, 5; zinc pentamethylenedithiocarbamate, 0.5; vulcanized at 115° (ring-shaped test pieces)

Min	60	90
$T_7$	77.5	96
$T_B$	187	163
$E_B$	853	794

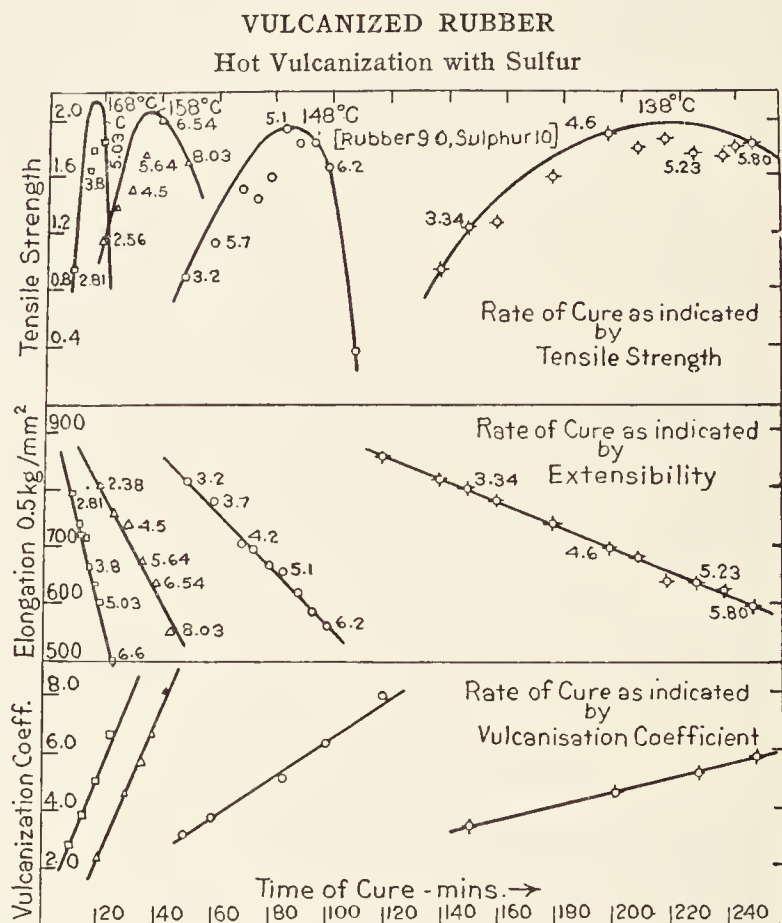


FIG. 14.—Vulcanization of simple rubber-S mixture (rubber, 90; S, 10) (165). Influence of temperature on rate of cure, ultimate tensile strength, stiffness, rate of combination of S and sharpness of tensile peak (ring-shaped test pieces).

## LOAD-STRAIN RELATIONS OF VULCANIZED RUBBER

TABLE 68.—PROGRESSIVE CHANGE ON VULCANIZING A SIMPLE RUBBER-S MIXTURE

Stock: rubber, 92.5; S, 7.5, vulcanized at 148° (ring-shaped test pieces) (165)

Period vulcanized, min	$T_B$	Number of samples	$E_B$	$E_{130}$	V. C.
75	75 ± 1.5	20	991 ± 3.9	1110?	2.86
80	90 ± 1.4	23	999 ± 2.2	1063?	
85	102 ± 1.4	29	990 ± 2.6	1040?	3.58
90	114.5 ± 0.8	58	992 ± 1.4	1018	3.77
95	122 ± 0.9	52	985 ± 1.8	994	
100	131.5 ± 0.9	39	969 ± 1.8	966.5	4.24
105	134.5 ± 0.8	38	957 ± 1.9	950	4.27
110	139 ± 0.8	58	944 ± 1.6	932	4.65
115	140.5 ± 0.7	50	928 ± 1.5	913	4.85
120	142 ± 0.6	60	916 ± 1.0	898	5.07
125	141 ± 0.8	34	901 ± 1.5	885.5	5.30
130	139 ± 0.9	28	885 ± 1.0	771	5.49
140	137	4			
150	130	4			



TABLE 69.—MOST PROBABLE VALUES ON VULCANIZING 341 SAMPLES OF RUBBER-S MIXTURE (RUBBER, 92.5; S, 7.5) AT 148° (130), cf. (54, 152, 165, 175)

V. C.	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
$T_4$ .....		12.4	13.9	15.4	16.9	18.4	19.9	21.4	22.9
$T_{8.5}$ .....	34.6	47.4	60.2	73.0	85.7	98.5	111.3	132.4	148.0
$T_B$ .....	64.3	77.6	91.0	104.4	119.0	128.4	138.2	137.3	115.5
$E_B$ .....	965	950	930	915	910	895	890	855	800

TABLE 70.—TEMPERATURE COEFFICIENT OF HOT VULCANIZATION WITH S (165), cf. (54, 130, 152, 175)

	Mixture A*	Mixture B†
Temperature range	128–168°	108–148°
Temperature coefficient based on:		
Combination of S.....	2.3	2.3
Extensibility of vulcanizate.....	2.3	2.5
Tensile strength of vulcanizate.....	2.4	2.4

\* Unaccelerated mixture: rubber, 90; S, 10.

† Accelerated mixture: rubber, 90; S, 10; aldehyde ammonia 0.125–1.0.

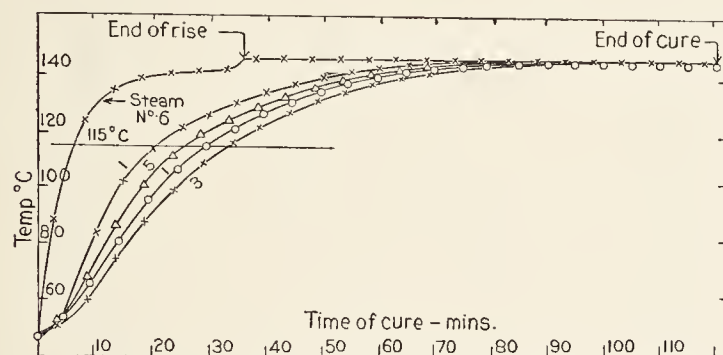


FIG. 15.—Temperature lag in vulcanization of a tire, vulcanized on air bags in steam autoclave for 2 hr at 146.3° (121). Temperatures at the following points in a 4-ply cord: (1) between second and third plies; (2) between second and third plies, under edge of the breaker; (3) same, under the center of the tread; (5) near the edge and on the top of the breaker.

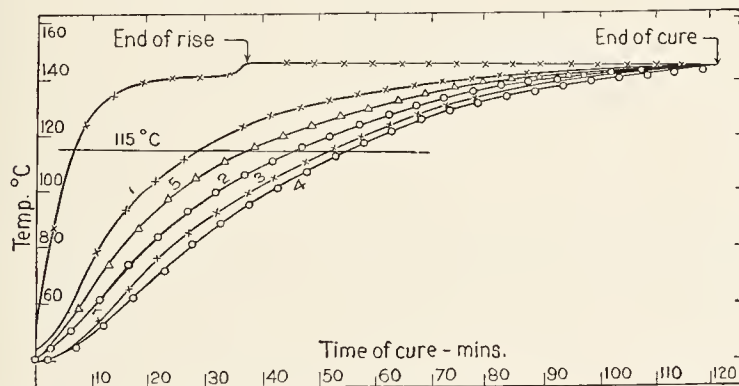


FIG. 16.—Vulcanized as in Fig. 15. Temperatures at following points in an 8-ply cover: (1) in the side between sixth and seventh plies; (2) between the sixth and seventh plies, under the edge of the breaker; (3) same, under the center of the tread; (4) same, under the edge of the breaker; (5) near the edge and on the top of the breaker.

TABLE 71.—INFLUENCE OF % OF S ON SIMPLE RUBBER-S MIXTURES

Mixtures vulcanized 90 min at 148° (130)

S, %	2.5	5	7.5	10	12.5	15	17.5	20
$T_B$ ....	29	63	99	124	57	23	25	62?
$E_B$ ....	900	894	894	766	431	198	183	384
V. C..	1.05	2.33	2.92	3.92	6.24	7.45	8.12	9.41

Vulcanized at 148° (199)

S, %	5	7	7.5	8	9	10
$E_{50}$ .....	1200	1000	965	925	870	790
$T_B$ .....	58	105	107	122	126	126
$E_B$ .....	1124	1016	984	964	911	840

TABLE 72.—INFLUENCE OF % OF S ON TIME OF CURE AT 148° AND ON TENSILE PROPERTIES AT OPTIMUM CURE (199)

S, %	Min	$T_B$	$T_{11.25}$	$E_B$	$E_{120}$	V. C.
7.5	75	133		911	891	
6	105	135		946	924	
5	120	135		1024	1001	4.41
3	120		40	>1125		2.81

#### Vulcanization by Other Means

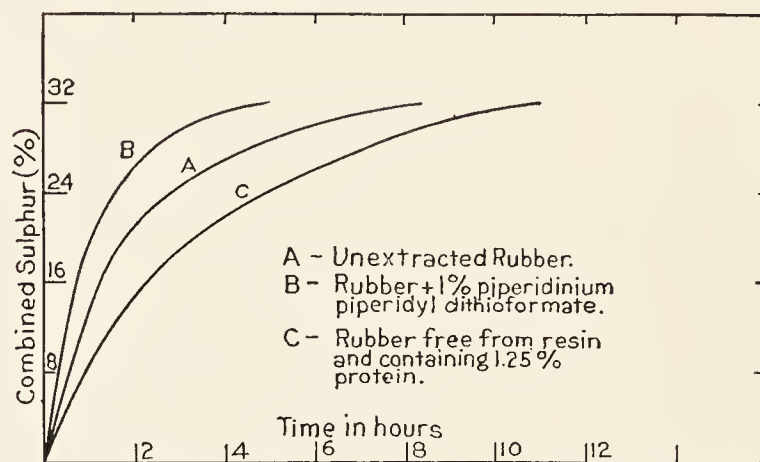


FIG. 17.—Vulcanization in solution. Rate of combination of S with (A) crepe, (B) crepe plus an accelerator and (C) crepe deprived of 52 % of its protein, on heating a 5 % solution in dichlorobenzene with 1000 % S (219); cf. (23, 84, 100, 157).

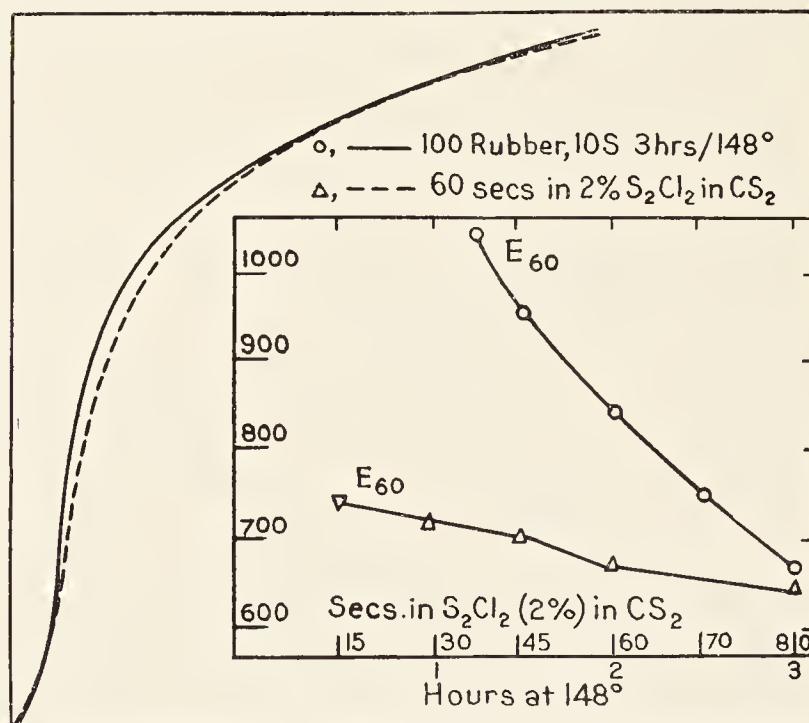


FIG. 18.—Comparison of the tensile properties (load-strain curve and stiffness) of rubber vulcanized by dipping in  $S_2Cl_2$  solution and by heating with S (ring-shaped test pieces) (230).

#### SULFUR MONOCHLORIDE (130, 230)

Sheets of calendered latex crepe, 1 mm thick, dipped in solutions of  $S_2Cl_2$  (1 – 5% in  $CS_2$ ) for not more than 120 sec:  $T_B$ , 84 to 127;  $E_B$ , 800 to 1000 (ring-shaped test pieces) (230).

NITRO COMPOUNDS AND ORGANIC PEROXIDES

*m*-Dinitrobenzenc. Stock: rubber, 100; PbO, 8; *m*-dinitrobenzene, 4; vulcanized 10 min at 147°: *T*<sub>B</sub>, 103; *E*<sub>B</sub>, 798 (30). Other nitro compounds and organic peroxides, *v.* (30).

TABLE 73.—MIXTURES OF SE AND S (228)

Composition of stock			Cure giving stiffest vulcanizate	
Crepe	S	Se	Time at 143°, min	<i>T</i> <sub>500</sub>
94	6.00	0.00	270	375
94	5.11	2.19	180	430
94	4.51	3.69	210	370
94	3.73	5.6	240	315
94	0.00	14.80	No cure in 300 min	

ULTRA-VIOLET RAYS (83)

NITROGEN SULFIDE (126)

PHYSICAL PROPERTIES

Tensile Properties

FACTORS INFLUENCING TENSILE PROPERTIES

TABLE 74.—INFLUENCE OF SHAPE OF TEST PIECE AND DIRECTION OF ITS AXIS WITH REFERENCE TO THE CALENDER DIRECTION (32)

	<i>T</i> <sub>B</sub>	<i>E</i> <sub>B</sub>	<i>T</i> <sub>B</sub>	<i>E</i> <sub>B</sub>	<i>T</i> <sub>B</sub>	<i>E</i> <sub>B</sub>
Sample No. ....	1		2		3	
Rings .....	151	635	119	675	74.5	525
Straight pieces:						
Longitudinal .....	192.5	630	146	640	84.5	480
Transverse .....	181.5	640	143.5	670	88.5	555
Sample No. ....	4		5		6	
Rings .....	107	435	36	285	51.5	320
Straight pieces:						
Longitudinal .....	130	410	48.5	320	62	315
Transverse .....	120	460	36	280	48.5	315

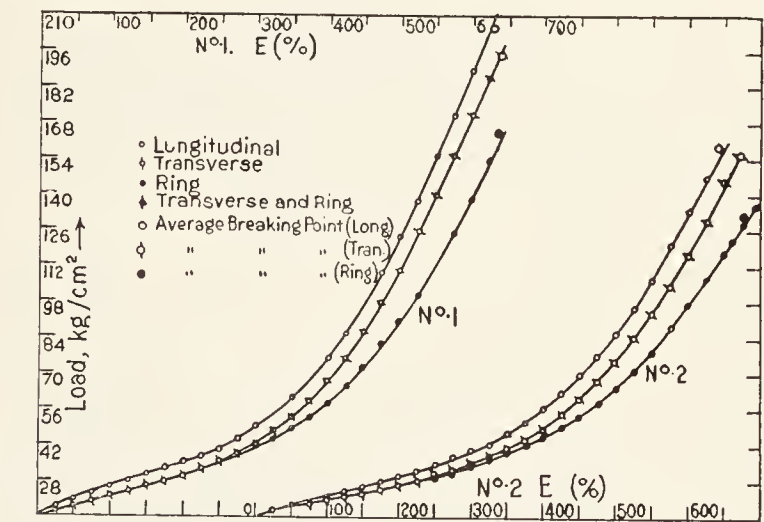


FIG. 19.—Load-strain curves of Samples 1 and 2 (Table 74) as determined by (a) ring test pieces, (b) straight test pieces cut longitudinally and (c) transversely (32).

TABLE 75.—INFLUENCE OF WIDTH OF STRAIGHT TEST PIECES (32)

Sample	Cover		Tube		Tube		Cover		Tube	
Width, mm	6.35	12.7	6.35	12.7	6.35	12.7	6.35	12.7	6.35	12.7
<i>T</i> <sub>B</sub> .....	110	102	151	137	72	67	51.5	48.5	175	144
<i>E</i> <sub>B</sub> .....	525	515	580	570	350	340	335	350	615	575

TABLE 76.—INFLUENCE OF WIDTH OF RING TEST PIECES (112)

Diameter, 44.6 mm; thickness, 4 mm								
	Higher-grade rubber				Lower-grade rubber			
Sample No. ...	1		2		3		4	
Width, mm. ...	<i>T</i> <sub>B</sub>	<i>E</i> <sub>B</sub>	<i>T</i> <sub>B</sub>	<i>E</i> <sub>B</sub>	<i>T</i> <sub>B</sub>	<i>E</i> <sub>B</sub>	<i>T</i> <sub>B</sub>	<i>E</i> <sub>B</sub>
2	158.9	808	105.8	611	18.9	182	25.2	187
4	117.7	806	97.1	624	18.8	193	27.3	203
6	97.4	809	87.5	628	17.2	183	26.0	199

TABLE 77.—INFLUENCE OF RATE OF STRETCHING (32)  
Straight test pieces

Rate of jaw separation (cm/min) .....	12.5	60	115	12.5	60	115
Higher-grade rubber						
Sample No. ....	5			2		
<i>T</i> <sub>B</sub> .....	175	188.5	190.5	133	136	138
<i>E</i> <sub>B</sub> .....	605	635	635	465	500	490
Lower-grade rubber						
Sample No. ....	3			4		
<i>T</i> <sub>B</sub> .....	26.3	30.1	32.5	23.8	27.3	30.1
<i>E</i> <sub>B</sub> .....	340	360	375	105	115	120

TABLE 78.—INFLUENCE OF TEMPERATURE ON THE STIFFNESS OF AN ACCELERATED STOCK (47)

Stock: smoked sheet, 100; S, 3; ZnO, 6; hexamethylenetetramine, 0.9; vulcanized 60 min at 141°

<i>t</i> , °C .....	21	24	27	30
<i>T</i> <sub>7</sub> .....	85	80	74	67

TABLE 79.—INFLUENCE OF HIGH TEMPERATURES (131)  
Stock: rubber, 92.5; S, 7.5; vulcanized to various extents at 147°

	<i>t</i> , °C	Time of heating prior to test, min	<i>T</i> <sub>B</sub>	<i>E</i> <sub>B</sub>	<i>T</i> <sub>8.5</sub>
Sample No. 1 (vulcanized 60 min; V. C. = 2.1)	24				31
	70	15	63	991	22
	100	15			20
	130	15			19
	147	2			19
	147	5	13	700	
Sample No. 2 (vulcanized 90 min; V. C. = 3.2)	147	15	14	678	
	26				49
	70	15	107	990	37
	100	15	104	1049	
	130	1	18	595	
	130	5	12	460	
Sample No. 3 (vulcanized 120 min; V. C. = 4.2)	147	1	13	500	
	147	5	12	465	
	147	5	14	512	
	23				79
	70	1	118	914	
	70	5	15	453	
Sample No. 3 (vulcanized 120 min; V. C. = 4.2)	70	5	17	491	
	100	1	14	423	
	100	5	13	395	
	130	1	12	381	
	130	5	12	379	
	147	1	13	384	

Load-Strain Curves for Vulcanized Rubber

Independently of state of cure, the load-strain curve for rubber-S stock is a coneoid expressed by

$$y = a - b \sin \alpha \tag{2}$$

$$x = n (a \cot \alpha - b \cos \alpha)$$

where *x* = load; *y* = strain; *a* = distance between pole and asymptote; *b* = distance between origin and asymptote; and *n* =



a constant fraction of corresponding abscissae of parent conchoid (137).

$$y = ex + a \sin^2 bx \quad (2)$$

where  $y$  = strain;  $x$  = load;  $e$ ,  $a$ ,  $b$  = constants for the rubber specimen in question, characterizing respectively the initial, the middle, and the ultimate elongations (39).

$$x = A \left\{ 1 - \frac{2}{l-b} \right\} e^{h(p-l)^2} \quad (3)$$

where  $x$  = load;  $l$  = length;  $b$  = breadth (taken as  $\frac{1}{\sqrt{l}}$ );  $h$ ,  $p$  = constants for the rubber specimen in question (118).

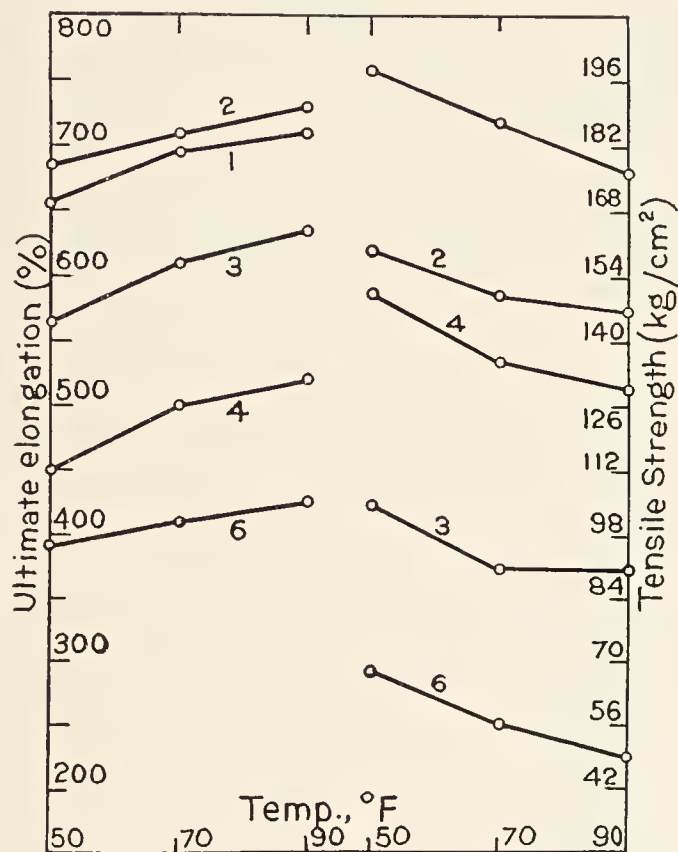


FIG. 20.—Influence of temperature on the tensile strength and ultimate elongation of five samples (32).

#### Stress-Strain Curve for Vulcanized Rubber

$$y = \frac{ax}{b+x} \quad (1)$$

where  $y$  = strain;  $x$  = load referred to unstrained cross section;  $a$  = distance of asymptote from axis;  $b$  = intercept cut off by tangent at origin on the asymptote.

The curve is a rectangular hyperbola, with asymptotes parallel to the axes, with the equations

$$y = a, x = -b.$$

Making the asymptotes the axes

$$x'y' = -ab \quad (82)$$

$$\text{Stress} = Ee + e/B^{\frac{l}{k}} \quad (2)$$

where  $e$  = elongation;  $l$  = original length;  $E$  = Young's modulus;  $B$  and  $k$  = constants (146).

#### Mechanical Hysteresis

TABLE 80

Extension and sub-permanent set in a succession of cycles of extension and retraction (24). Pure gum rubber, sp. gr. 0.985, loaded at rate of 0.8 kg/cm<sup>2</sup> per 27 sec.

Cycle No.	1	2	3	4	5	6	7	8
Extension produced, %	516	568	590	604	617	627	636	643
Sub-permanent set, %	20	23	25	28	28	28	28	28

Extension, sub-permanent set, energy absorption, energy of hysteresis in succession of cycles of various amplitudes (80).

Extension in a series of cycles. Extension =  $a + b \log$  (No. of cycle) where  $a$  = extension in second cycle;  $b$  = increment of extension in subsequent cycles (140).

Influence of amount of extension on amount of hysteresis. In general, the shorter the cycle, the smaller the energy of hysteresis (cf. Fig. 23).

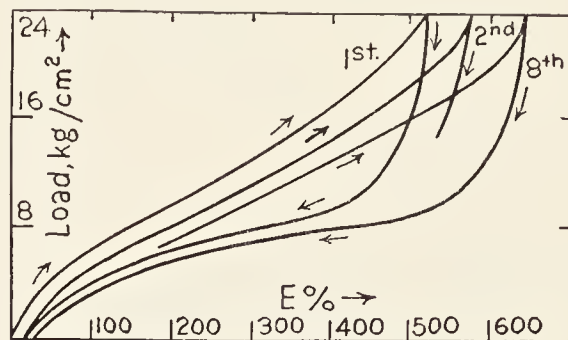


FIG. 21.—Load-strain curve for cycles Nos. 1 and 8 and part of cycle No. 2 (Table 80) (24).

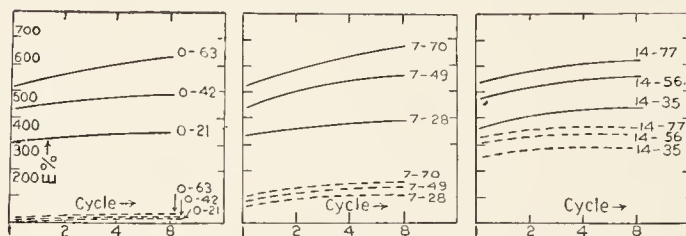


FIG. 22.—Relation between cycle number and max. (solid lines) and min. (dotted lines) extension for cycles between various loads. Stock: rubber (smoked sheet), 94 vols.; S, 3 vols.; MgO, 1 vol.; carbon black, 2 vols.; vulcanized 60 min at 149°. Load expressed in kg/cm<sup>2</sup> (80).

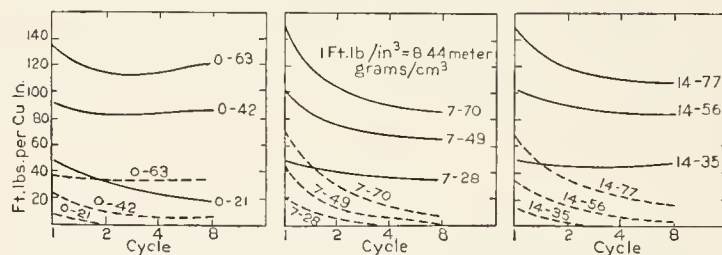


FIG. 23.—Relation between the cycle number and energy absorption (solid lines) and energy of hysteresis (dotted lines) for cycles between various loads. Load expressed in kg/cm<sup>2</sup> (80).

TABLE 81

Pure gum rubber subjected to a succession of cycles of different lengths, each cycle being repeated until the course of the load-strain curves was constant (24).

Cycle No.	Amplitude kg/cm <sup>2</sup>	Difference between elongation at same load during extension and retraction, %
1	0-4	61
2	0-8	167
3	0-12	286
4	0-16	533

Influence of rate of loading and unloading. The higher the rate of loading and of unloading, the smaller the extension and the greater the hysteresis (24).

Influence of state of cure and of the presence of a filler on energy absorption (Figs. 26 and 27) and energy of hysteresis (Figs. 28 and 29) in a succession of cycles of extension and retraction (80).

Stock A (by volume): rubber, 94; S, 3; MgO, 1; carbon black, 2.  
Stock B (by volume): rubber, 63; S, 2; MgO, 1; carbon black, 2; whiting, 32.

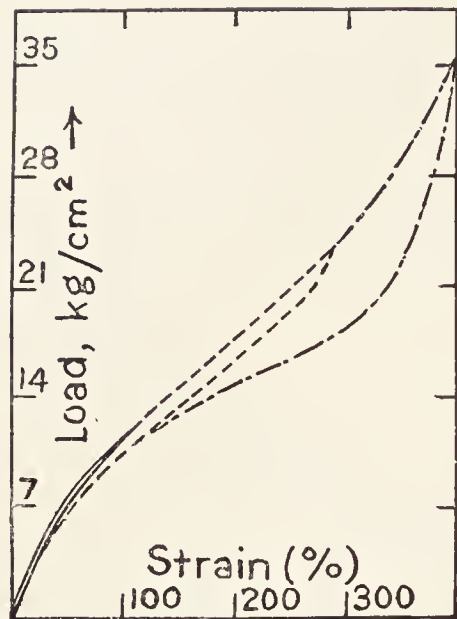


FIG. 24.—Pure gum rubber subjected to hysteresis cycles of different lengths (141).

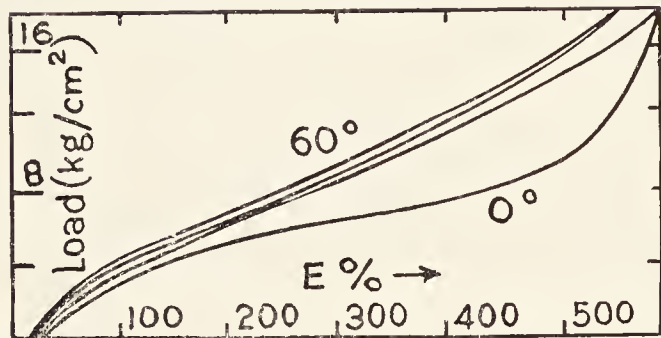


FIG. 25.—Influence of temperature on extension (24). Pure gum rubber, sp. gr. 0.985, loaded to 18.4 kg/cm² at 0° and 60°.

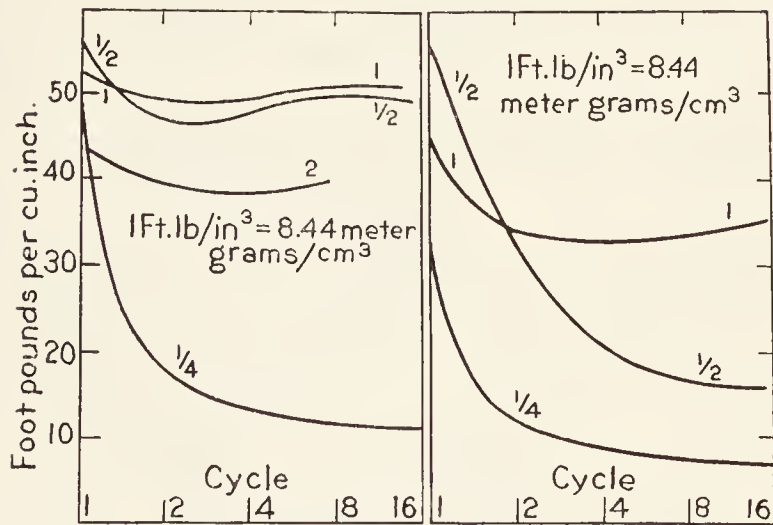


FIG. 26.—Stock A vulcanized for periods from 0.25 to 2 hr at 149° (80).

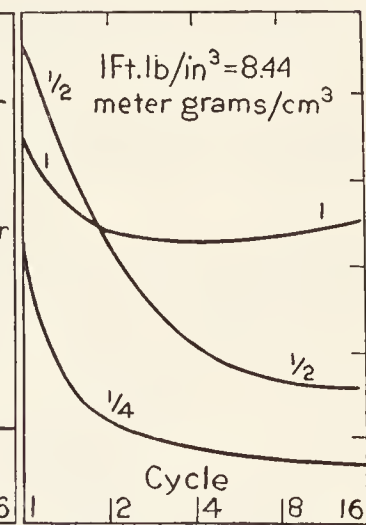


FIG. 27.—Stock B vulcanized for periods from 0.25 to 1 hr at 149° (80).

Influence of compounding ingredients on Poisson's ratio for rubber (174). ( $P_v$ ,  $P_t$ ,  $P_w$ : Poisson's ratio from measurements of volume, thickness, width, respectively.)

1.  $P_t = P_w = P_v$  at elongations up to 200: carbon black, ZnO.
2.  $P_t$  does not equal  $P_w$ ;  $P_v = 0.5$ .

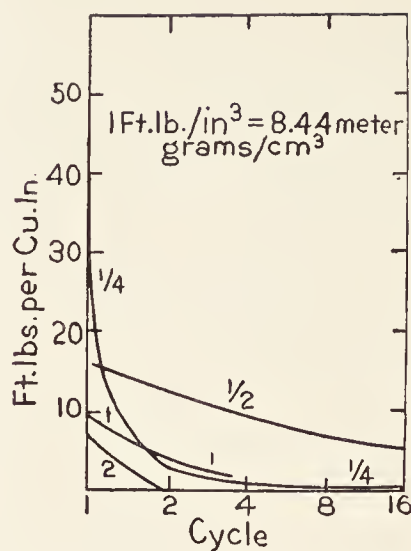


FIG. 28.—Stock A vulcanized for periods from 0.25 to 2 hr at 149° (80).

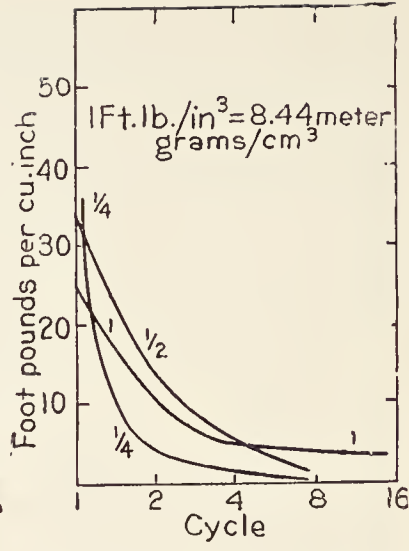


FIG. 29.—Stock B vulcanized for periods from 0.25 to 1 hr at 149° (80).

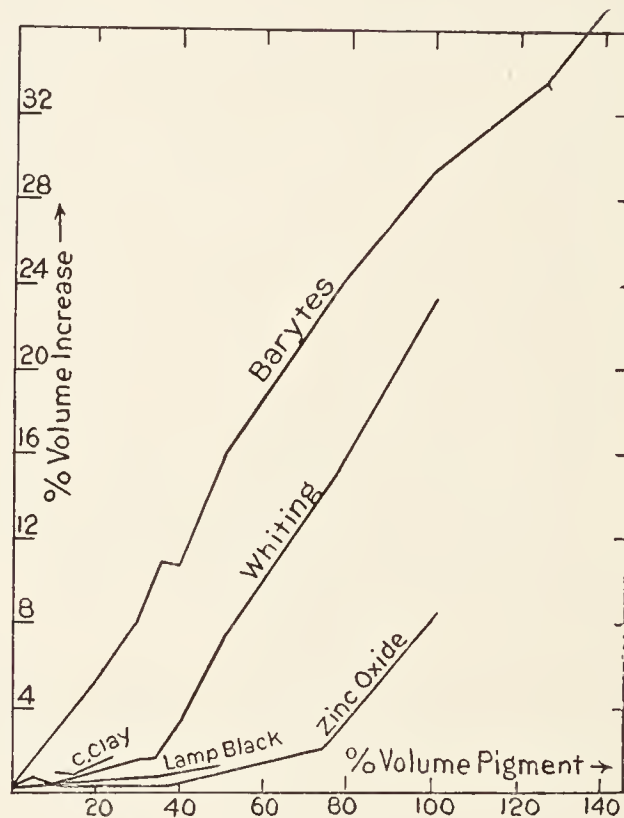


FIG. 30.—Increase in volume produced by straining to 100 % elongation stocks containing various volumes of barytes, china clay, lampblack, whiting and ZnO. Basal stock: rubber, 100; S, 5; litharge, 30 (139).

3.  $P_w = P_t$ ;  $P_v < 0.5$  at 300 %: barytes, lithopone.
4.  $P_w$  does not equal  $P_t$ ;  $P_v < 0.5$ : tripoli at high elongations (cf. Fig. 32).

	At 25 % elongation		
	$P_t$	$P_w$	$P_v$
Magnesium carbonate.....	0.72	0.31	0.51
Clay.....	0.69	0.32	0.505
Tripoli.....	0.61	0.39	0.50



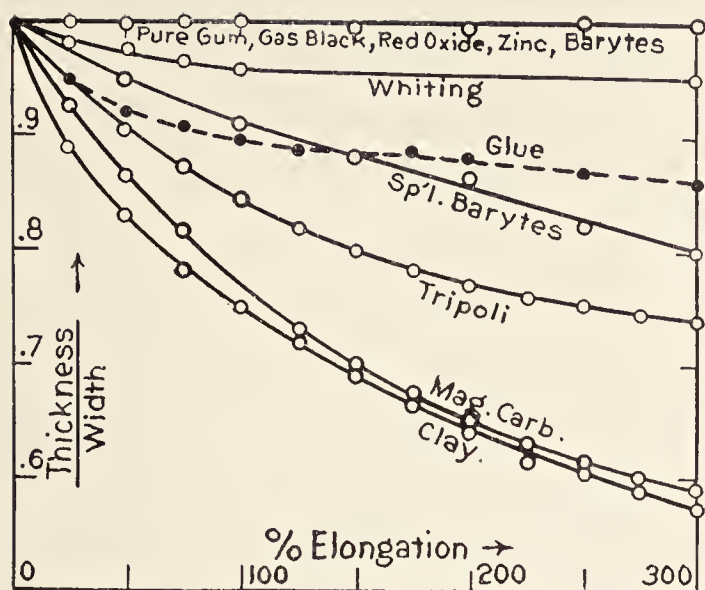


FIG. 31.—Effect of strain on the ratio thickness: width as influenced by various compounding ingredients (20 vols. per 100 vols. rubber) (174).

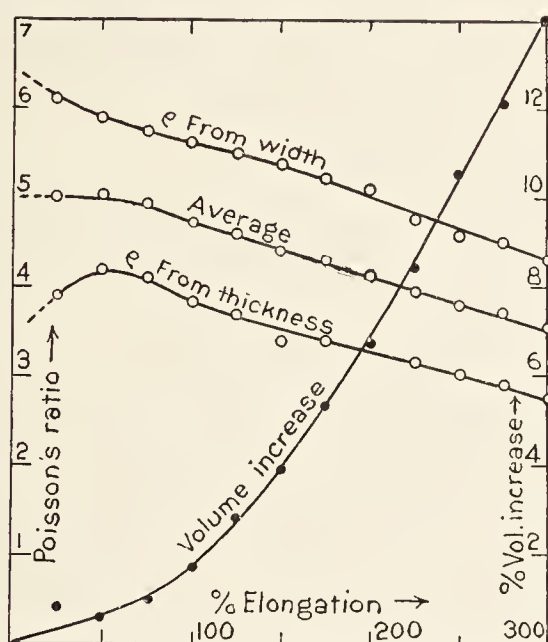


FIG. 32.—Effect of tripoli on Poisson's ratio and on increase in volume at various extensions (174). Stock contains 20 vols. tripoli per 100 vols. rubber.

#### Load-Compression Relations. Pure Gum Rubber

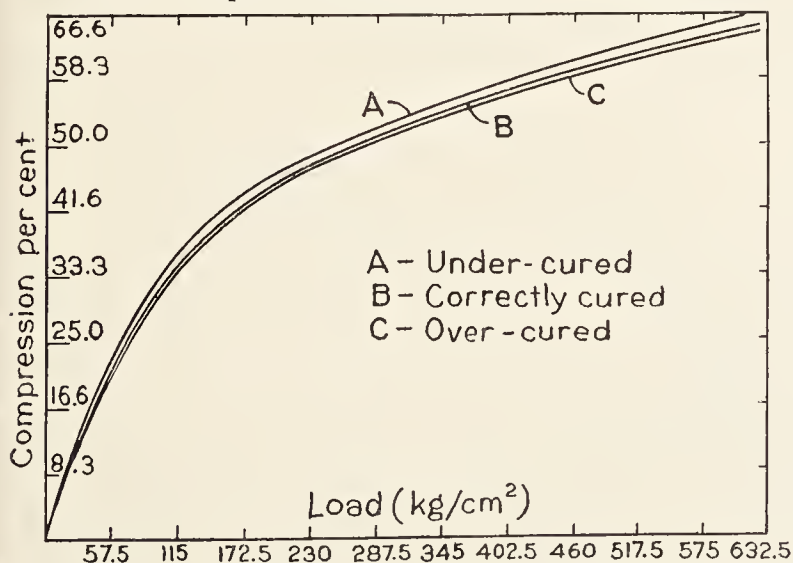


FIG. 33.—Load-compression curves for the stock: rubber, 100; S, 10; in various states of cure (17).

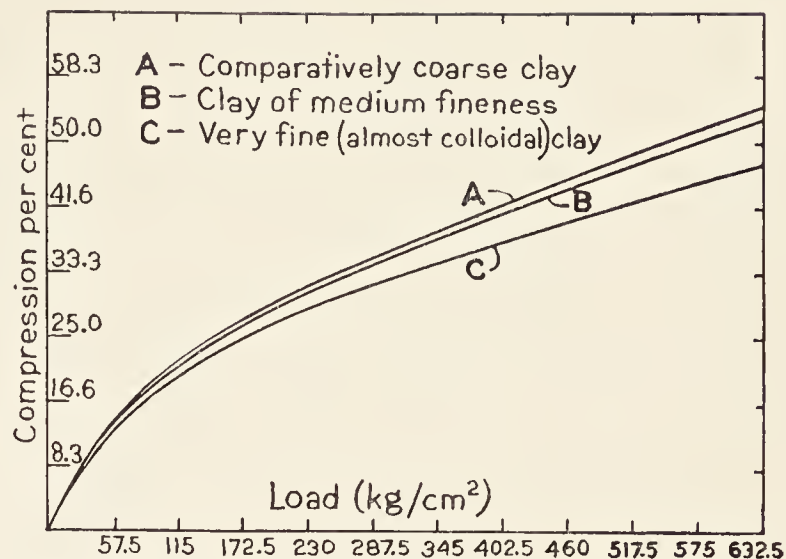


FIG. 34.—Load-compression curves for the stock: rubber, 100; china clay, 20; S, 10; ZnO, 5; diphenylguanidine, 1; using clay of different degrees of fineness (17).

#### Hardness

**Definitions.**—Plastometer number: the depression in hundredths mm produced by a steel sphere when the force against a surface of the rubber is increased from 85 to 1085 g, and then maintained for 60 sec (79).

Modulus of hardness: the force in dynes producing a depression of 1 cm<sup>3</sup> (79).

See p. 270 for Figs. 35–39, giving illustrative values.

#### Resistance to Tearing

TABLE 82.—INFLUENCE OF STATE OF CURE ON RESISTANCE TO TEAR (231)

Stock: rubber, 92.5; S, 7.5; vulcanized at 145°

Time of cure, min. . . . .	30	45	60	75	90	105	120	135	150
Resistance to tear, kg/cm <sup>2</sup> . . . . .	5.6	7.7	9.8	11.6	13.3	16.8	13.3	11.9	11.2

#### Compressibility

**Compressibility.**— $92.95 \times 10^{-6}$  of the original volume per kg/cm<sup>2</sup> (40). Equal to that of bronze (2), cf. (105).

**Volume Elasticity** (107).—Soft, gray rubber (sp. gr., 1.289;  $T_B$ , 58;  $E_B$ , 890): 14 000 kg/cm<sup>2</sup>. Red rubber (sp. gr., 1.407;  $T_B$ , ca. 58;  $E_B$ , 630): 8000 kg/cm<sup>2</sup>. Gray rubber (sp. gr., 2.340;  $T_B$ , 58;  $E_B$ , 340): 66 000 kg/cm<sup>2</sup>.

#### Thermal Properties

**Expansion.**—Coefficient of cubical expansion of:

(a) Sample of vulcanized rubber (sp. gr., 0.996), 2.25° above to 2.25° below its maximum density: 0.000526 (88).

(b) Sample of black vulcanized rubber (sp. gr., 0.90166 at 17.4°; S content, 2.5 to 3 %) at 0–60.7°: 0.000763 (105).

(c) Gray rubber: 0.000562 (105).

**Specific Heat.**—Above mentioned sample (a): 0.415 (88).

**Conductivity.**—Vulcanized rubber, crepe, smoked sheet, etc. (45–100°): 0.00032 cal/sec/cm<sup>3</sup> (227).

#### Absorption

##### ABSORPTION OF ORGANIC VAPORS

TABLE 84.—ABSORPTION (g/g RUBBER) BY RAW RUBBER AND A RUBBER STOCK (RUBBER, 100; S, 12.5) VULCANIZED TO VARIOUS DEGREES (93)

V. C.	0.0	1.2	2.0	3.5	4.4	6.4
Carbon tetrachloride . . . . .	0.99	0.975	0.99	0.98	0.99	1.05
Benzene . . . . .	0.98	0.895	0.87	0.86	0.86	0.85
Carbon disulfide . . . . .		0.64	0.65	0.63	0.64	0.67

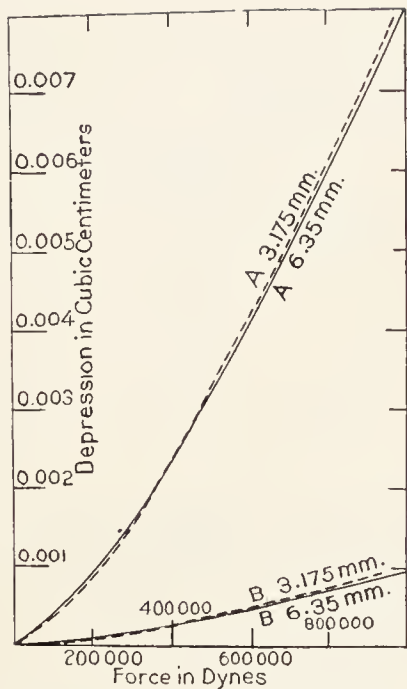


FIG. 35.—Force-volume depression curves for 2 samples of vulcanized rubber (steel balls 3.175 and 6.35 mm in diameter) (79).

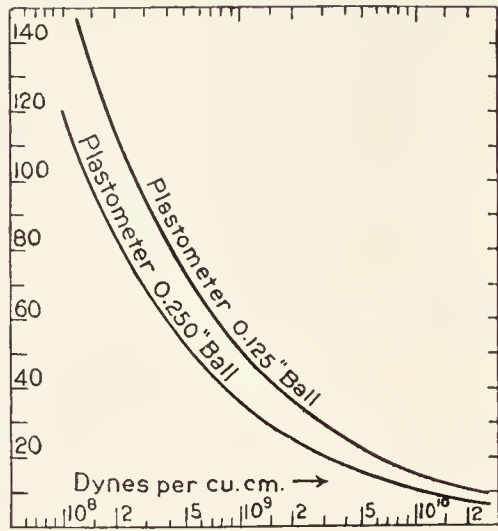


FIG. 36.—Relation between plastometer number and modulus of hardness (79).

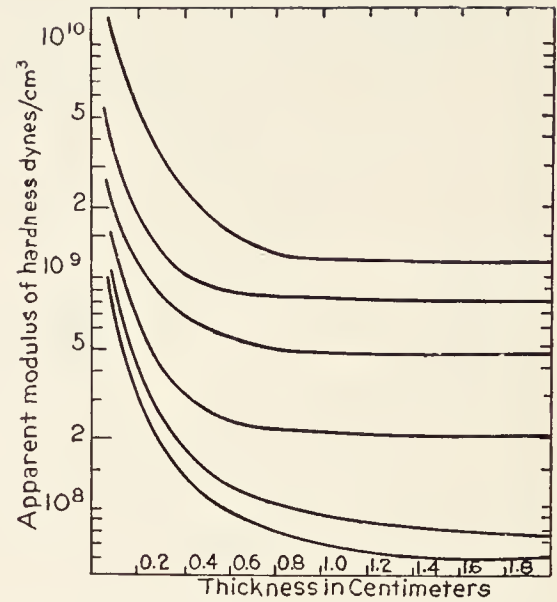


FIG. 38.—Influence of thickness of thin specimens on apparent hardness as determined by the plastometer (6 samples) (79).

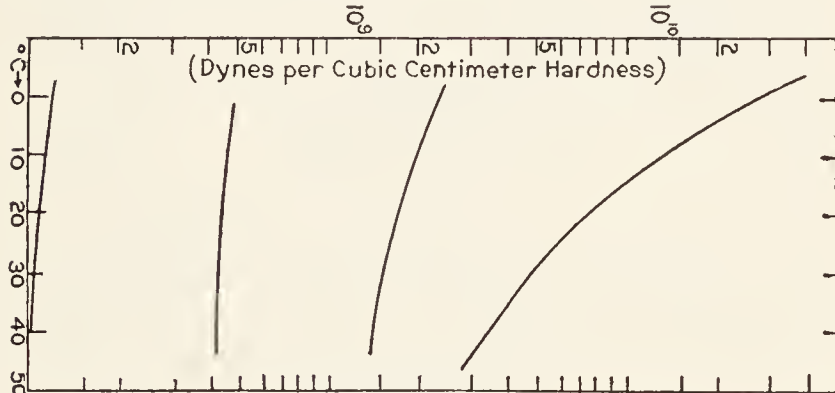


FIG. 37.—Change of modulus of hardness with temperature (4 samples) (79).

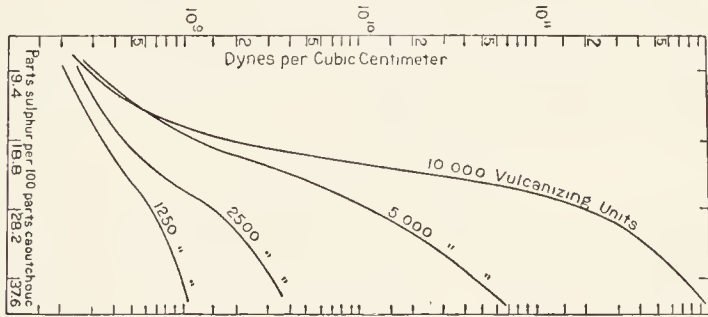


FIG. 39.—Modulus of hardness and degree of vulcanization (vulcanizing unit = (time of vulcanization at  $t^\circ$ )  $\times 1.1^{150-t}$ ) (79).

ABSORPTION OF WATER

TABLE 85.—ABSORPTION BY RAW RUBBER OF WATER FROM MOIST AIR (130), cf. (210)

Relative humidity, %		100	89	79	49	100	89	79	49
Type	Resin %	% absorption at 16°				% absorption at 30°			
Hevea sheet...	3.32	1.85	0.88	0.31	0.23	2.88	0.76	0.44	0.24
Hevea crepe...	3.43	2.80	0.89	0.39		4.54	1.06	0.37	
Castilloa.....	5.2	0.62	0.28			1.57	0.23	0.16	
Congo.....	16.7	6.02	2.12	0.9		15.8	2.58	1.26	0.42

Vulcanized rubber shows the same absorption from water vapor as from liquid water (22).

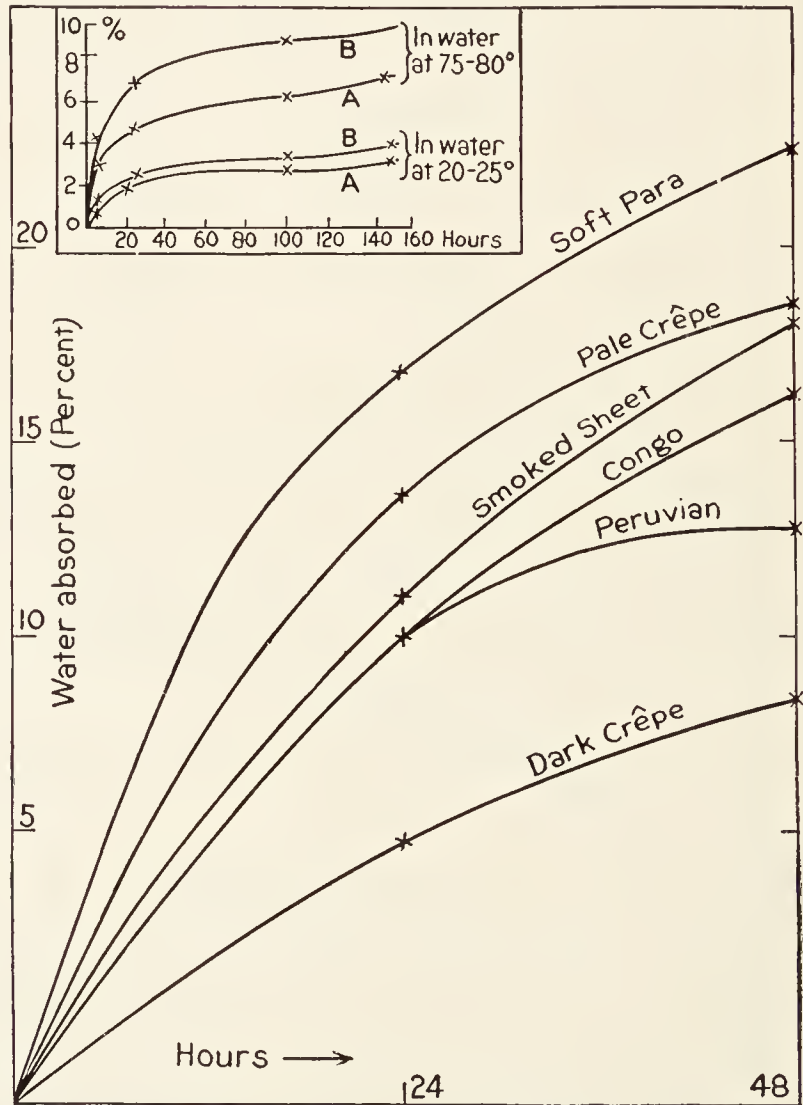


FIG. 40.—Various types of raw rubber in distilled water at 80-90° (94).

FIG. 41 (Insert).—Water absorption by cut sheet. Effect of temperature on (A) raw rubber, (B) cold vulcanized (94).



TABLE 86.—WATER ABSORPTION BY VARIOUS TYPES OF RUBBER  
g/cm<sup>2</sup> surface of sheets 0.35 mm thick (22)

Type	<i>t</i> , °C	Immersion, hr	Absorption
Pale crepe.....	24	200	0.0356
	70	50	0.072
Smoked sheet.....	70	50	0.103
Fine Para.....	70	50	0.087
Latex sprayed.....	70	50	0.33
Vulcanized rubber*.....	24	50	0.0070–0.0097
	70	50	0.035–0.045
Hard rubber†.....	70	100	0.0137
Hard rubber‡.....	70	100	0.0110
Gutta-Percha.....	24	200	0.0122

\* Stock: rubber, 24; ZnO, 18; whiting, 12; litharge, 3; S, 1.5; cured 60 min at 135°. Crepe, smoked sheet and fine Para used.

† Stock: rubber, 30; S, 17.5; *p*-nitrosodimethylaniline, 0.3; cured 120 min at 148°.

‡ Stock: rubber, 60; S, 35; cured 240 min at 148°.

TABLE 87.—ABSORPTION BY SAMPLES IMMersed 18 WEEKS AT  
15–25° (117)

Type	Medium	% absorption
Para rubber.....	Distilled water	31.77
Para rubber.....	Sea water	2.80
Gutta-Percha*.....	Distilled water	1.13–1.44†

\* 4 samples; resin content: 20.3–46.3 %.

† Calculated on the gutta.

TABLE 88.—INFLUENCE OF DEGREE OF VULCANIZATION ON WATER  
ABSORPTION (94), cf. (22)

Stock: crepe, 100; S, 7; MgO, 5

Time of cure at 143°, min.....	15	30	60	120
Combined S, %.....	0.62	1.17	2.37	4.12
	% water absorbed			
Immersed 6 hr at 70–80°.....	4.45	3.6	2.8	2.3
Immersed 24 hr at 70–80°.....	5.32	4.74	3.9	2.9
After 48 hr more at 20°.....	13.2	10.5	7.8	5.9

Temperature coefficient for absorption of water by vulcanized rubber: 1.32–1.44 fold for each 10° rise in temperature (22).

Influence of pressure: water absorption is unaffected by increase of pressure from 1 to 5 atmospheres (22).

### Imbibition of Liquids

TABLE 89.—IMBIBITION BY RAW RUBBER

cm<sup>3</sup> liquid by 1 cm<sup>3</sup> fine Para in 10 days at room temperature (151)

Carbon tetrachloride..	12.05	Benzene.....	9.05
Chloroform.....	11.30	Xylene.....	8.89
Carbon disulfide.....	10.07	Ethyl ether.....	4.82
Toluene.....	9.52	Methyl alcohol.....	0.13

g liquid by 1 g fine Para under pressure of 1.12 kg/cm<sup>2</sup> (124)

Carbon tetrachloride..	11.06	Benzene.....	4.41
Chloroform.....	9.31	Cymene.....	4.38
<i>sym.</i> -Dichloroethylene	7.35	Cumene.....	4.13
Thiophene.....	5.32	Ethylene chloride....	2.71
Toluene.....	4.65	Ether.....	2.40

TABLE 90.—IMBIBITION BY VULCANIZED RUBBER

cm<sup>3</sup> liquid by 1 cm<sup>3</sup> rubber (sp. gr., 0.997; ash, 2; total S, 12.54; combined S, 1.28 %) in 24 hr at 17° (65)

Chloroform.....	9.64	Nitrobenzene.....	1.36
Carbon disulfide.....	8.11	Ethyl acetate.....	0.33
Toluene.....	7.40	Acetone.....	0.15
Xylene.....	6.35	Acetic acid.....	0.12
Benzene.....	5.86	Amyl acetate.....	0.085
Turpentine.....	5.52	Ethyl alcohol.....	0.025
Benzyl chloride.....	4.39	Methyl alcohol.....	0.02
Petroleum ether.....	4.38	Ethyl alcohol (96 %)....	0.011
Kerosene.....	3.67	Water.....	0.005
Ethyl ether.....	3.43		

cm<sup>3</sup> liquid by 1 cm<sup>3</sup> "black rubber tubing," sp. gr., 1.06 (160)

Chloroform.....	7.37	Ethyl ether.....	3.09
Carbon disulfide.....	6.52	Ethyl acetate.....	0.71
Benzene.....	5.87	Acetone.....	0.21

g liquid by 1 g rubber, (stock: rubber, 90; S, 10; vulcanized 75 min at 148°) in 48 hr (214)

Benzene.....	3.63	Aniline.....	0.13
Toluene.....	3.84	Methylaniline.....	1.49
<i>m</i> -Xylene.....	3.01	Dimethylaniline.....	3.02
<i>d</i> -Pinene.....	2.57	<i>o</i> -Toluidine.....	0.69
Tetrahydronaphthalene..	5.22	Diethylamine.....	6.24
<i>n</i> -Pentane.....	0.72	Piperidine.....	17.75
Carbon tetrachloride....	8.50	Acetic acid.....	0.16
Chloroform.....	6.51	<i>n</i> -Butyric acid.....	1.57
Trichloroethylene.....	8.10	Dichloroacetic acid....	14.20
Tetrachloroethane.....	8.19	Acetyl chloride.....	5.96
Tetrahydroethylene.....	6.47	Ethyl acetate.....	0.49
Pentachloroethane.....	8.02	Propyl acetate.....	1.27
Bromobenzene.....	6.17	<i>n</i> -Butyl acetate.....	1.43
Benzyl chloride.....	3.01	Isoamyl acetate.....	1.73
Phenyl mustard oil.....	3.21	Ethyl benzoate.....	2.26
Nitrobenzene.....	1.46	Cyclohexanol.....	0.58
Benzonitrile.....	2.20		

TABLE 91.—FACTORS INFLUENCING IMBIBITION

Degree of vulcanization: cm<sup>3</sup> CCl<sub>4</sub> imbibed by 1 g rubber (stock: rubber, 100; S, 12.5; vulcanized to various degrees) (93)

V. C.	1.20	2.0	3.6	4.4	6.4
Hours immersed					
1	8.09	5.86	5.12	4.04	3.40
6	24.10	14.30	9.82	7.74	5.12
24	29.00	16.10	10.40	7.87	5.40

Temperature: cm<sup>3</sup> C<sub>6</sub>H<sub>6</sub> imbibed in 10 hr by 1 g rubber (stock: rubber, 100; S, 12.5; vulcanized to various degrees) (93)

V. C.	1.2	2.0	3.6	4.4	6.4
<i>t</i> °C					
40	8.73	6.30	5.16	4.33	3.30
50	9.00	6.55	5.37	4.60	3.60
80	10.70	7.56	5.85	5.20	4.00

Pressure: g C<sub>6</sub>H<sub>6</sub> imbibed by 1 g raw fine Para (124)

kg/cm <sup>2</sup> .....	0.72	1.12	2.12	3.12	5.12
Imbibition.....	5.14	4.41	3.28	2.71	2.09

For similar data for toluene, eumene, eymene, ether, chloroform, carbon tetrachloride, ethylene chloride, *sym.*-tetrachloroethane, *sym.*-dichloroethylene and thiophene, *v* (124).

TABLE 92.—VELOCITY OF IMBIBITION  
Velocity of swelling (under a pressure of 1.12 kg/cm<sup>2</sup>)

$$k = \frac{1}{z} \log_e \frac{\omega_{\infty}}{\omega_{\infty} - \omega}$$

where  $k$  = a constant,  $z$  = time in minutes,  $\omega_{\infty}$  = imbibition at equilibrium,  $\omega$  = imbibition at time  $z$ ,  $t = 17-18^{\circ}$  (124).

Liquid	Benzene	Cumene	Chloroform	Thiophene
$k$	0.0019	0.0021	0.00057	0.00083

#### Solubility of Solids in Rubber

TABLE 93.—SULFUR (90)

In raw rubber: at 33°, 1.01; at 55°, 1.96 g/100 g raw rubber

In vulcanized rubber:

$t, ^{\circ}\text{C}$	Rubber: S ratio	hr cured at 141°	V. C.	Solubility g S/100 g stock
40	100:10	1	1.46	1.48
		2	2.98	1.45
		3	4.34	1.53
		4	6.54	1.61
		5	7.95	1.69
55	100:10	1	1.46	2.13
		2	2.98	2.24
		3	4.34	2.39
		4	6.54	2.56
55	100:30	3	5.47	2.36
		4	8.72	2.94
		5	13.92	3.00
75	100:30	3	5.47	3.22
		4	8.72	4.25
		5	13.92	5.42
		6	16.91	5.90

#### SELENIUM (228)

In raw rubber: <0.05 % at 80°C.

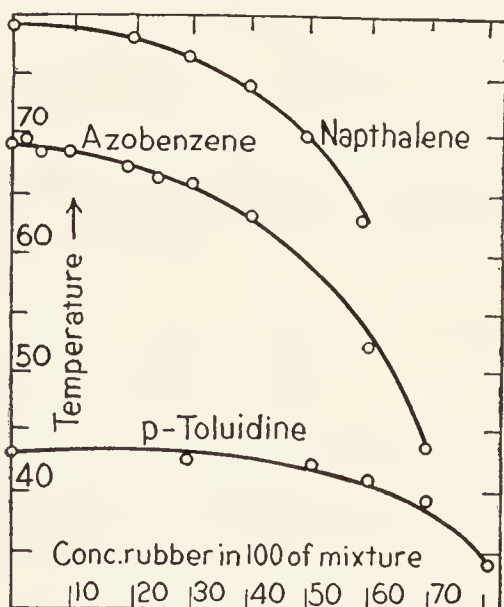


FIG. 42.—Solubility of naphthalene, azobenzene and *p*-toluidine in raw rubber (27).

#### Permeability to Gases and Vapors

Permeability is proportional to the partial pressure of the gas and to the thickness of the rubber (44, 59, 89, 229).

#### SPECIFIC PERMEABILITY

Unit.—cm<sup>3</sup> gas/min/cm<sup>2</sup> area/cm thickness.

Hydrogen.— $20.4 \times 10^{-6}$  at 25° (vulcanized rubber on balloon fabric) (59).  $(5.520 + 0.876t) \times 10^{-6}$ , range 12.8 to 30.7° (sp. gr., 0.9455 at 18 to 20°) (89).

Carbon Dioxide.— $(-5.084 + 2.928t) \times 10^{-6}$ , range 9 to 33° (sp. gr., 0.9455 at 18 to 20°) (89).

TABLE 94.—PERMEABILITY RELATIVE TO HYDROGEN AT SAME TEMPERATURE

In (59) samples are vulcanized rubber on balloon fabric. In (44) samples are vulcanized, probably by sulfur chloride

Gas	Relative permeability	$t^{\circ}, \text{C}$	Lit.
Hydrogen.....	1		
Oxygen.....	0.445	25	(59)
	0.337	20	(44)
	0.500	25	(45)
	0.45		(72)
Nitrogen.....	0.160	25	(59)
	0.12	20	(45)
	0.18		(72)
Argon.....	0.23	25	(45)
	0.26		(125)
Helium.....	0.65	25	(59)
Air.....	0.230	25	(59)
	0.194	17	(44)
	2.91	25	(59)
Carbon dioxide.....	2.76	17	(44)
	2.8		(45)
	2.48		(89)
	2.47		(72)
Nitrous oxide.....	4.54	17	(44)
Ammonia.....	8	25	(59)
	11.4	17	(44)
Water vapor.....	55	25	(59)
Liquid water.....	105	25	(59)
Methyl chloride.....	18.5	25	(59)
Ethyl chloride.....	198	25	(59)

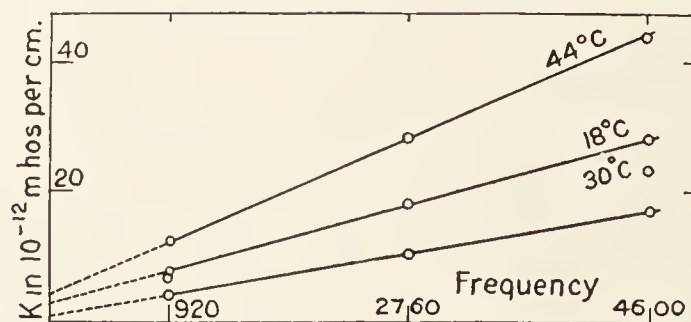


FIG. 43.—Variation of conductivity for raw india rubber with temperature and frequency (62).

#### Electrical Properties

##### RAW RUBBER, GUTTA-PERCHA AND BALATA

TABLE 95.—ELECTRICAL PROPERTIES OF RAW RUBBER (42)

Type	Age, mo	Number of samples	Dielectric constant at 1000 ~	Power factor, %	Resistivity (10 <sup>8</sup> meg-ohm-cm)
Fine Para.....		13	2.43	0.14	35
Pale crepe.....		6	2.43	0.16	50
Pale crepe*.....		3	2.36	0.29	40
Smoked sheet....	3	6	2.53	0.19	3
Smoked sheet....	15	3	2.38	0.16	10
Smoked sheet*....	12	3	2.35	0.29	60
Cameta.....		5	2.56	0.28	10
Guayule.....		2	2.69	0.51	60

\* Thoroughly washed and dried.



TABLE 96.—ELECTRICAL PROPERTIES OF GUTTA-PERCHA AND BALATA (42)

	% composition*			H <sub>2</sub> O, %	Dielectric constant at 1000 ~	Power factor at 1000 ~	Resistivity (10 <sup>8</sup> megohm-cm)
	Gutta	Resin	Mechanical impurities				
1. Gutta-Percha refined by acetone extraction.....	99.0		1.0	0	2.56	0.09	370
2. Gutta-Percha (Tjipetir plantation).....	89.2	9.3	1.5	>0	2.60	1.1	65
3. No. 2 after drying.....	89.2	9.3	1.5	0	2.61	0.23	45
4. Gutta-Percha, refined. .	79.9	19.3	0.8		2.78	0.35	60
5. Gutta-Percha, commercial.....	57.3	39.2	3.5	2.5	4.13	3.1	
6. No. 5 after drying.....	57.3	39.2	3.5	0	3.01	1.8	25
7. Resin from Gutta-Percha	0.0	100.0			3.27		25
8. Balata, commercial sheet	44.8	39.8	15.4		3.48	2.3	

\* On dry weight.

TABLE 97.—INFLUENCE OF FREQUENCY ON ELECTRICAL PROPERTIES OF RAW RUBBER AND GUTTA-PERCHA (42)

	Dielectric constant				Power factor		Resis- tivity (10 <sup>8</sup> meg- ohm-cm)
	Alternating current		Direct current		At 1000 ~, %	At 60 ~, %	
			0.6 sec charge, discharge				
	1000 ~	60 ~	0.1 sec	1.0 sec			
Pale crepe.....	2.38	2.40	2.65	2.70	0.3	0.5	30
Gutta-Percha*	2.62	2.63	2.81	2.87	0.2	0.3	50
Gutta-Percha†	2.82	2.84	3.01	3.07	0.4	0.5	60

\* Tjipetir.

† Refined commercial.

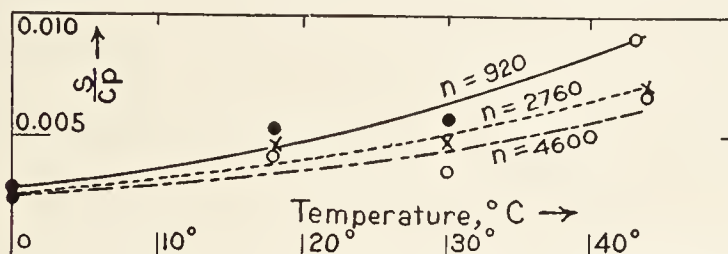


FIG. 44.—Variation of S/ep (power factor) with temperature and frequency for raw india rubber condenser (62).

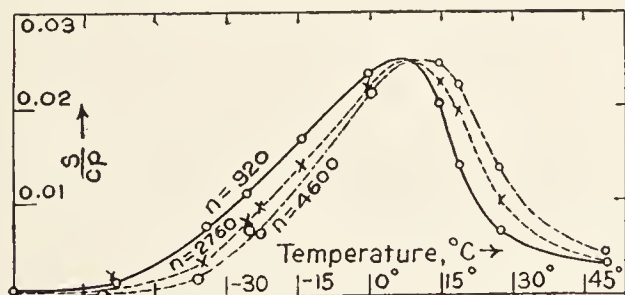


FIG. 45.—Variation of S/ep (power factor) with temperature and frequency for Gutta-Percha from -75 to 50°C (62).

TABLE 98.—INFLUENCE OF TEMPERATURE AND FREQUENCY ON ELECTRICAL PROPERTIES (62)

	Raw rubber			Gutta-Percha		
	920	2 760	4 600	920	2 760	4 600
Frequency.....	18	18	18	15	15	15
Temperature, °C.....	18	18	18	15	15	15
Dielectric constant for alternating current.....	2.60	2.60	2.60	2.86	2.86	2.86
Temperature coef- ficient { per °C range	-0.062	~0.062	-0.062	0.105	0.124	0.133
	0 to 43°	0 to 44°	0 to 44°	-14 to 50°	-14 to 50°	-14 to 50°
Resistivity, alternating current, megohm-cm.....	145 000	54 500	35 400	33 700	10 200	5 600
Power factor, %.....	0.005	0.005	0.004	0.020	0.023	0.025
Specific conductance for frequency n, microhm-cm.....	1.53 + 0.0058n			-16.9 + 0.04n (at 19°)		

TABLE 99.—INFLUENCE OF FREQUENCY AND TEMPERATURE ON CONDUCTANCE OF GUTTA-PERCHA (62)

Frequency	Conductance (κ) in bi-mhos (10 <sup>12</sup> mhos) per cm <sup>2</sup>										
	t, °C	-75	-53	-34	-26	-14	0	15	19	27	50
920	κ	1	2	10	15	22	33	30	20	10	4
2760	t, °C	-75	-54	-35	-25	-14	0	15	19	27	50
	κ	3	9	14	35	53	91	97	87	46	14
4600	t, °C		-56	-36	-25	-14	0	15	19	27	50
	κ		3	13	49	80	146	177	163	97	32

## SOFT VULCANIZED RUBBER

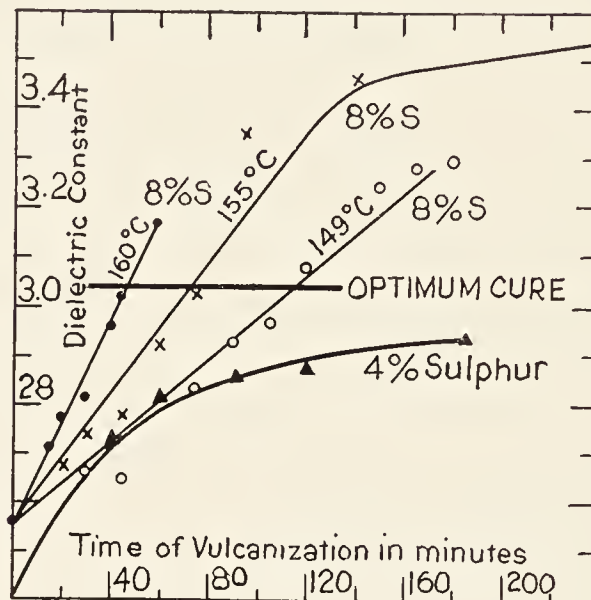


FIG. 46.—Dielectric constant at 1000 cycles; pure gum mixture (smoked sheet, 96; S, 4 and smoked sheet, 92; S, 8) vulcanized for various periods of time at various temperatures (42).

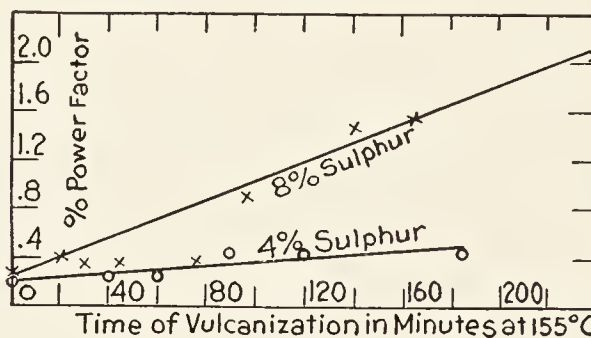


FIG. 47.—Power factor for samples described in Fig. 46 (42).

Resistivity: ranges from  $10 \times 10^8$  to  $150 \times 10^8$  megohm-cm irregularly (42)

TABLE 100 (42)

Composition				$t$ , °C	Cure, min†	Dielectric constant at 1000 ~	Power factor, %	Resistivity (10 <sup>8</sup> meg-ohm-cm)
Rubber	Accel.*	ZnO	S					
Without free sulfur								
98	1	1	0	155	45	2.42	0.87	185
					90	2.40	0.81	195
92	3	5	0	126	15	2.49	0.42	20
					40	2.48	0.41	24
88	5	10	0	155	4	2.60	0.90	200
					12	2.59	0.80	220
85	5	10	0	126	20	2.66	0.47	20
					40	2.62	0.45	20
80	10	10	0	126	20	2.84	0.50	5

TABLE 100 (42).—(Continued)

Composition				t, °C	Cure, min*†	Dielectric constant at 1000 ~	Power factor, %	Resistivity (10 <sup>8</sup> meg- ohm-cm)
Rubber	Accel.*	ZnO	S					
With free sulfur								
91.75	3	5	0.25	126	20	2.48	0.40	27
					35	2.45	0.26	45
92.5	2	5	0.5	126	10	2.51	0.23	150
					40	2.48	0.35	80
92.75	0.75	5	1.5	126	10	2.49	0.35	150
					25	2.49	0.34	210
90.75	0.25	5	4	126	15	2.60	0.23	90
					30	2.78	0.41	10

\* Tetramethylthiuram disulfide.

† Extremes of range.

TABLE 101.—INFLUENCE OF FREQUENCY (42)

Composition	Dielectric constant				Power factor		Resistivity (10 <sup>8</sup> meg-ohm-cm)
	Alternating current		Direct current 0.6 sec charge, discharge		At 1000 ~, %	At 60 ~, %	
1000 ~	60 ~	0.1 sec	1.0 sec				
1. Rubber, 96; S, 4.....	2.89	2.90	3.25	3.32	0.35	1.2	20
2. Rubber, 90.75; S, 4; ZnO, 5; tetramethylthiuram disulfide, 0.25..	2.67	2.67	2.86	2.94	0.20	0.2	80
3. (2) + ZnO, 75.....	9.76	10.3	11.9	13.1	1.9	4.8	0.5
4. (2) + carbon black, 20.	6.12	8.61	10.3	12.4	7.5	10.5	0.4

TABLE 102.—INFLUENCE OF TEMPERATURE AND FREQUENCY (62)

Frequency.....	920	2 760	4 600
Temperature, °C.....	17	17	17
Dielectric constant for alternating current.....	2.73	2.71	2.71
Temperature coefficient range (−14 to 83°).....	−0.150	−0.130	−0.140
Resistivity, alternating current, megohm-cm.....	342 300	103 000	38 100
Power factor, %.....	0.2	0.2	0.4
Specific conductance for frequency n, micro-microhm-cm..	2.0 + 1180 × 10 <sup>−12</sup> n <sup>2</sup> .		

TABLE 103.—INFLUENCE OF TEMPERATURE AND FREQUENCY ON THE CONDUCTANCE OF SOFT VULCANIZED RUBBER (62)

Frequency	Conductance (κ) in bi-mhos (10 <sup>12</sup> mhos) per cm <sup>3</sup>												
920	t, °C	−76	−63	−42	−32	−23	−14	0	17	41	60	83	
	κ	2	4	32	50	26	19	7	3	8	12	16	
2760	t, °C	−76	−63	−42	−33	−23	−14	0	17	42	61	83	
	κ	4	8	53	141	102	76	31	10	18	29	41	
4600	t, °C	−76	−63	−42	−32	−24	−14	0	17	44	60	84	
	κ	3	9	62	220	205	158	57	26	26	43	57	

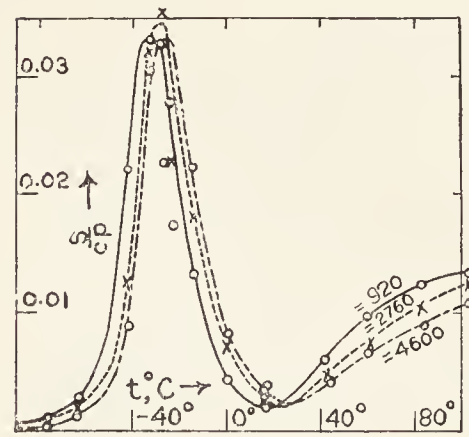


FIG. 48.—Variation of S/ep (power factor) with temperature and frequency for soft vulcanized rubber from −90 to 100°C (62).

INFLUENCE OF COMPOUNDING INGREDIENTS

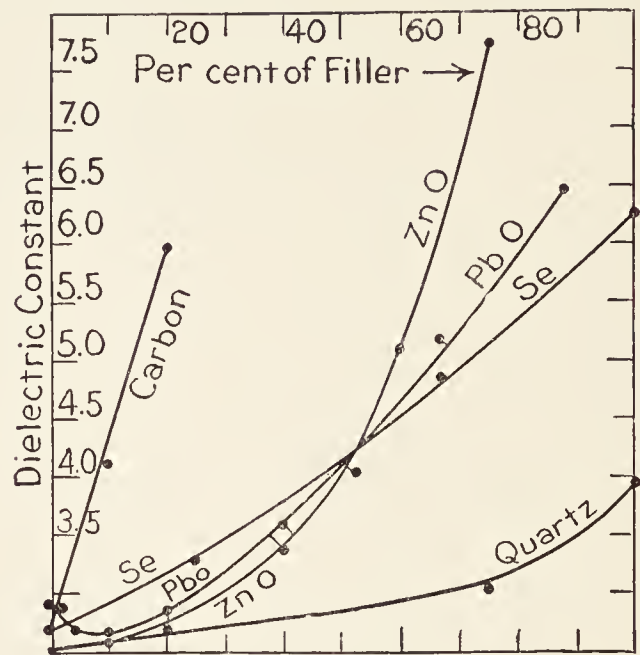


FIG. 49.—Influence of carbon black, ZnO, litharge, Se and quartz on dielectric strength (42).

In the case of ZnO, quartz, and Se, “% of filler” means the parts of filler by weight added to the following basal mixtures:

	Rubber	S	ZnO	Palm oil	Tetra-methylthiuram disulfide
Zinc oxide.....	93.75	2		4	0.25
Quartz.....	92.75	2	1	4	0.25
Selenium.....	90.75	4	5		0.25

In the case of litharge “% filler” means the percentage present in the following series of mixtures:

Litharge.....	0	4	10	20	40	66	88
Rubber.....	96	88	82	74	52	22	9
Sulfur.....	4	4	4	6	8	11	1
Ozokerite.....		4	4				
Palm oil.....						1	2

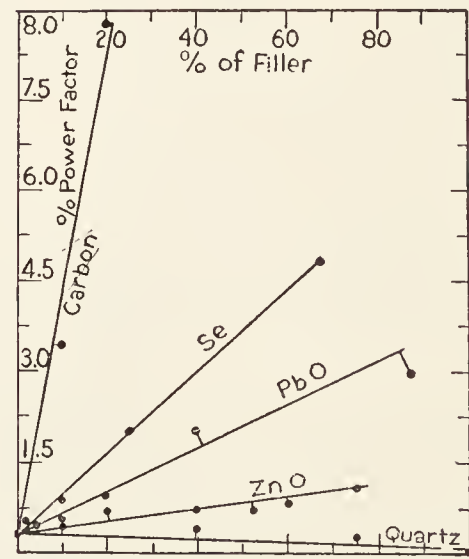


FIG. 50.—Influence of filler on the power factor at optimum cure (42); cf. note to Fig. 49.

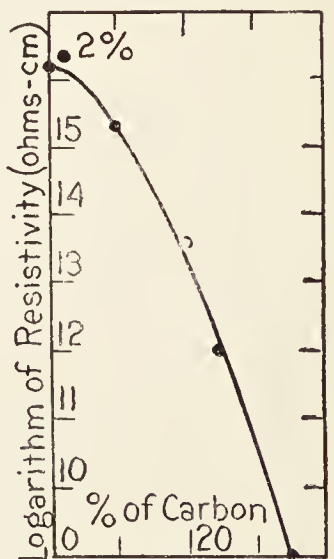


FIG. 51.—Influence of carbon black on the resistivity (42).



TABLE 104.—INFLUENCE OF BARYTES, "TITANOX," IRON OXIDE, TELLURIUM, CHINA CLAY AND ASBESTINE (42)

Stock No. 1: smoked sheet, 90.75; S, 5; ZnO, 4; tetramethylthiuram disulfide, 0.25 %. Stock No. 2: smoked sheet, 90.75; S, 5; ZnO, 4; diphenylguanidine, 1 %

Rubber mixture, %	Dielectric constant, 1000 ~	Power factor, %	Resistivity (10 <sup>8</sup> megohm-cm)
No. 1.....	2.70	0.32	90
No. 1 + barytes, 45.....	3.37	1.1	20
No. 1 + titanox, * 50.....	3.77	1.1	13
No. 1 + iron oxide, 46.....	3.61	1.39	30
No. 1 + tellurium, 25.....	3.20	0.50	85
No. 2.....	2.62	0.75	190
No. 2 + china clay, 49.....	3.27	1.13	170
Rubber, 41; S, 2; ozokerite, 5.4; tetramethylthiuram disulfide, 0.1; asbestos, 50 ..	4.24	2.1	14

\* Approximate composition: titanium dioxide, 25; barium sulfate, 75 %.

## INFLUENCE OF SOFTENERS

In a stock cured by the aid of tetramethylthiuram disulfide, the following softeners have little effect on the dielectric constant: ozokerite, 10; vaseline, 10; beeswax, 10; stearic acid, 10; palm oil, 5 parts.

The following increased the dielectric constant from 2.67 to the figures noted: *p*-coumarone resin, 10, to 2.80; mineral rubber, 33, to 2.88 (42).

## HARD RUBBER

TABLE 105.—ELECTRIC STRENGTH (63, 63.5)

	Thickness, mm	Electric strength, kilovolt-mm	<i>t</i> , °C
1. Rubber with 35 % S*.....	0.5	150	10-20
2. Medium quality.....	0.5	36	10-20
3. Medium quality.....	1.0	25	10-20
		18	60
	2.0	18	10-20
		11	60
4. Medium quality.....	1.0	45	10-20
		32	100
5. Switch handle quality....	0.5	26	10-20

\* Sp. gr., 1.201.

TABLE 106.—ELECTRICAL PROPERTIES OF VARIOUS GRADES OF HARD RUBBER (3)

	Admiralty sheet (U. S.)	G. P. O. sheet* (U. S.)	Sheet†	Rods and tubes‡	Radio panels and parts*
Specific gravity.....	1.22	1.20	1.19	1.18	1.46
Tensile strength, kg/cm <sup>2</sup> ....	635	530	440	480	395
Compressive strength, (kg/cm <sup>2</sup> )    to laminations, 0.5 in. cube.....	338	282	245	265	220
Compressive strength (kg/cm <sup>2</sup> ) ⊥ to laminations....	359	300	249		237
Elongation, %.....	6.8	4.5	4.5	5.1	3.3
Electric strength (v/mm) alternating current.....	367	351	325	370	322
Resistivity (megohm-cm) × 10 <sup>6</sup> .....	26.6	30.2	32.9	628	100
Dielectric constant at radio frequencies.....					4.3
Water absorption (%) (24 hr at 50°).....	0.03	0.04	0.05	0.04	0.08

\* Mean of 3 samples.

† Mean of 4 samples.

‡ Mean of 5 samples.

TABLE 107 (42)

	Dielectric constant, 1000 ~	Power factor, %	Resistivity, megohm-cm
Rubber, 71.4; S, 28.6.....	3.50	0.4	110 × 10 <sup>8</sup>

TABLE 108.—INFLUENCE OF TEMPERATURE AND FREQUENCY (62)

Frequency.....	920	2 760	4 600
Dielectric constant for alternating current.....	3.17	3.15	3.14
Temperature coefficient range (0 to 84°).....	0.360	0.310	0.290
Resistivity, alternating current, megohm-cm.....	148 500	38 500	23 100
Power factor, %.....	0.5	0.5	0.5
Specific conductance for frequency <i>n</i> , micro-microhm-cm..	0 + 0.01 <i>n</i>		

TABLE 109.—INFLUENCE OF HEAT AND IMMERSION ON THE ELECTRICAL PROPERTIES OF A MEDIUM GRADE OF HARD RUBBER (63.5)

	Electric strength, kv/mm at 10-20°			Volume resistivity, megohm-cm			Surface resistivity, megohm		
	Im-mersed	Sample No. 6	Sample No. 8	Im-mersed	Sample No. 6	Sample No. 8	Im-mersed	Sample No. 6	Sample No. 8
Normal.....		45	29		5 × 10 <sup>8</sup>	4 × 10 <sup>8</sup>		16 × 10 <sup>6</sup>	44 × 10 <sup>3</sup>
Water.....	24 hr	32	29	1 wk	5 × 10 <sup>8</sup>	5 × 10 <sup>8</sup>	1 wk	1.8 × 10 <sup>6</sup>	0.8 × 10 <sup>6</sup>
Brine.....	24 hr	37	35	1 wk	5 × 10 <sup>8</sup>	5 × 10 <sup>8</sup>	1 wk	1.7 × 10 <sup>6</sup>	27 × 10 <sup>3</sup>
H <sub>2</sub> SO <sub>4</sub> *.....				1 wk	5 × 10 <sup>8</sup>	5 × 10 <sup>6</sup>	1 wk	15 × 10 <sup>6</sup>	1.2 × 10 <sup>6</sup>
Oil.....	24 hr		30	1 wk	3.5 × 10 <sup>8</sup> at 100°	5 × 10 <sup>8</sup> at 50°	1 wk	26 × 10 <sup>6</sup> at 100°	5 × 10 <sup>6</sup> at 50°
Air.....				6 hr	1 × 10 <sup>8</sup> at 100°	5 × 10 <sup>8</sup> at 50°	6 hr	4 × 10 <sup>8</sup> at 100°	4 × 10 <sup>8</sup> at 50°

\* Specific gravity, 1.21.

TABLE 110.—INFLUENCE OF COMPOUNDING INGREDIENTS (120)  
Stock: fine Para, 65; S, 35

Ingredient added	Sp. gr. of mixture	Electric strength, kv/mm
None.....	1.201	150
Talc.....	1.298	128
Soft palm pitch.....	1.185	118
Waste, soft grade.....	1.192	115
Hard palm pitch.....	1.224	108
Waste, hard grade.....	1.199	92
Caramba wax.....	1.171	78
Factice (vulcanized oil).....	1.187	72
Zinc oxide.....	1.335	69

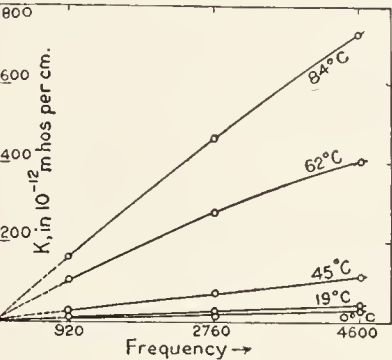


FIG. 52.—Variation of conductivity of ebonite with temperature and frequency (62).

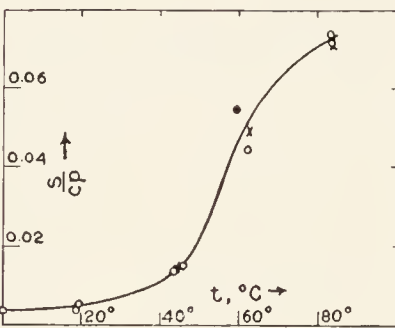


FIG. 53.—Variation of S/ep (power factor) for an ebonite condenser with temperature and frequency. Black dots denote 920, crosses 2760, and small circles 24 600 p. p. s. (62).

MILLING

TABLE 111.—INFLUENCE OF TIME OF MILLING ON PLASTICITY (78)

79 kg rubber (half sheet, half crepe) milled on a 214 cm fast mill. Extrusion time is the time in min required to extrude a length of 2 cm through the orifice of a Griffiths' plastometer at 85°.

Time, min.....	12.5	18	25	32.5	45	60
Extrusion time.....	2.77	2.05	1.72	1.47	1.23	0.97

TABLE 112.—INFLUENCE OF TIME AND TEMPERATURE OF MILLING ON PLASTICITY (172)

Milling conditions			Milling conditions		
Time, min	Temp., °C	k	Time, min	Temp., °C	k
13	100	4.7	30	40	2.0
25	100	3.7	60	40	1.6
55	100	3.0	120	40	1.3

TABLE 113.—INFLUENCE OF TIME OF MILLING ON VISCOSITY OF RUBBER SOLUTIONS (25, 130)

Time of milling, min.....	0	10	15	
Viscosity number {	Fine hard Para...	72.1	24.8	15.2
	Latex crepe.....	49.6	20.4	16.4

---

Time of milling, min.....	2.5	5	10	15	20	30	40	50	60
Relative viscosity of 2% soln...	1900	540	150	110	90	70	65	60	59

TABLE 114.—TIME IN MIN REQUIRED TO PRODUCE A GIVEN DEGREE OF PLASTICITY

Influence of (a) distance between the rolls ("nip") and (b) the size of the batch of rubber on the time required to reduce rubber to a given degree of plasticity and the temperature acquired during milling in the case of a 214 cm mill, with a friction ratio of 1:1.5 and a surface speed of the front roll of 25.4 m per min (78).

Extrusion time, min	45.4 kg batch				79 kg batch			
	2.2	1.45	1.3	1.2	2.2	1.45	1.3	1.2
Nip, mm								
4.3	11	28.5	33	36.5	19	46.5	53	57.5
3.57	13	25	28	31	21.5	42.5	50	53.5
2.78	9	17.5	20.5	22.5	15.5	34.5	39.5	43
1.98	ca. 9	15.5	18	20	16	32.5	39	44.5
1.19	ca. 13	16.5	18.5	20	17	34	39	42
0.40		13.5	15.5	17	16.5	29		

Extrusion time, min	113 kg batch				147 kg batch			
	2.2	1.45	1.3	1.2	2.2	1.45	1.3	1.2
Nip, mm								
4.3	36				49			
3.57	31	60			41			
2.78	23	51	58	63	35.5	63		
1.98	30	51	57.5	62	35	59		
1.19	29	46.5	51	54	35.5	53	57.5	60

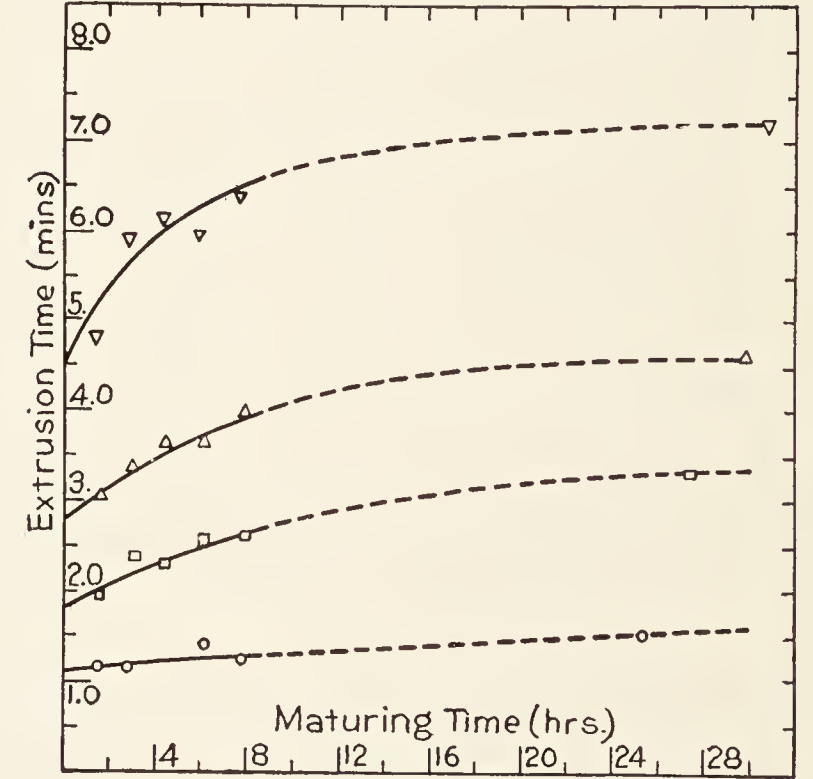


FIG. 54.

Recovery from Milling

Figure 54 shows the recovery from milling (expressed as maturing time/plasticity) of the same batch of typical pale crepe rubber milled to different degrees of plasticity and then allowed to remain at room temp. in the form of rolls 25 cm long X 7.5 cm diam. (78); the plasticity is expressed as the extrusion time in a Griffiths' plastometer (cf. Table 111).

Figure 55 shows the recovery of rubber (2 samples) from milling as shown by the viscosity of solutions (2 g in 97 cm<sup>3</sup> CS<sub>2</sub>) after storage for various periods (123).



Figure 56 shows the influence of temperature of storage on recovery from milling (3 samples). "Hot" storage: 22.75 kg held at 42° in the form of a roll 25.5 cm long; "cold" storage: slices 6.3 cm thick cooled in water immediately after milling and held at room temp. (78).

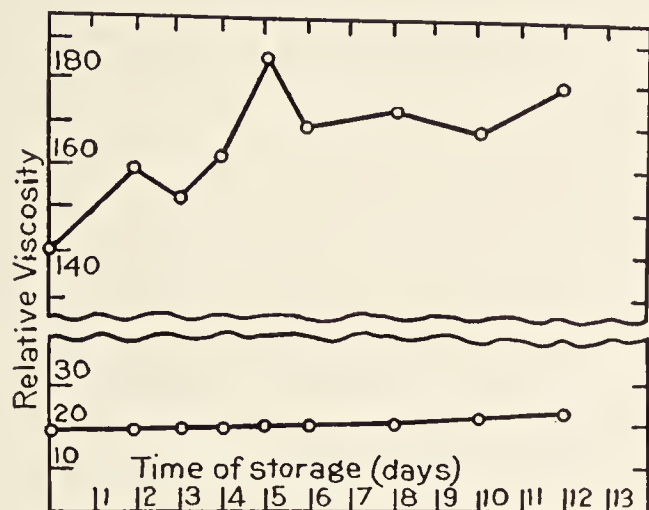


FIG. 55.

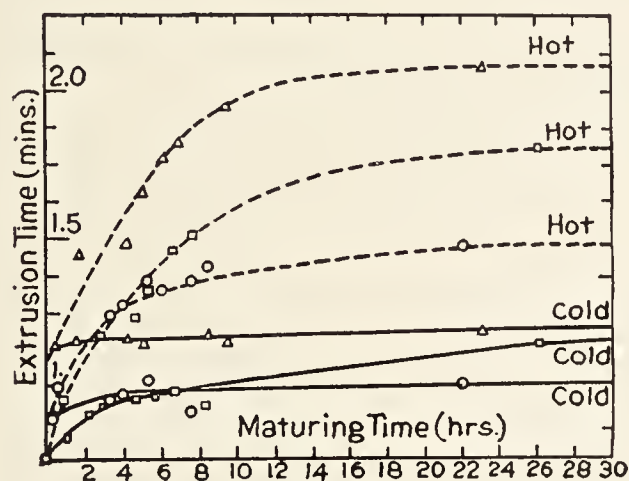


FIG. 56.

#### Calender Grain

Difference in tensile properties in the direction of calendering and at right angles to it (*cf.* Poisson's ratio).

*Raw Rubber.*—Sheet calendered on cloth: longitudinal direction,  $T_B$ , 7.1;  $E_B$ , 95. Transverse direction,  $T_B$ , 1.4;  $E_B$ , 533 (127).

TABLE 115

*Vulcanized Rubber.*—Stock calendered on cloth or on a cold calender roll (224).

$X$  = rotation of the load-strain curve from the strain axis expressed as excess energy of resilience shown by test pieces cut along the calendar direction compared with pieces cut transversely to the calendar direction, *i.e.*,

$$\left[ \frac{\int_0^x \Delta T dE}{\int_0^x T \text{ (with grain) } dE} \right] \times 100,$$

the upper limit of integration being taken at 90 % of the mean  $E_B$ .

$Z$  = displacement of the load-strain curve expressed as the extent to which the curve for test pieces in the calendar direction has to be shifted along the strain axis to coincide with the curve for test pieces cut transversely to the calendar direction.

*a*, vulcanized, wrapped, on mandrel; *b*, vulcanized in mold with no overflow.

Composition of stocks: (1) rubber, 97; S, 3 (by volumes); (2) rubber, 92; S, 4; ZnO, 4; (3) rubber, 90; antimony sulfide containing 40 %  $\text{CaSO}_4$ , 10; (4) rubber, 73; S, 3.5; litharge, 3; whiting, 18; gas black, 2.5; (5) rubber, 52; S, 8; litharge, 2; whiting, 35; gas black, 3.

Stock	1	2	3	4	5
<i>a</i> { <i>X</i> .....	9	5	21	27	18
<i>a</i> { <i>Z</i> .....	10	12	30	45	40
<i>b</i> { <i>X</i> .....	12	5	15	23	11
<i>b</i> { <i>Z</i> .....	30	8	25	50	35

Comparison of grain in calendered and in extruded rubber after vulcanization. Stock No. 3 (above) *a*: calendered, *X*, 21; *Z*, 30; extruded, *X*, 11; *Z*, 10 (224).

#### SOFTENERS

TABLE 116.—EFFECT OF SOFTENERS ON PROPERTIES OF CURED AND UNCURED STOCK (RING-SHAPED TEST PIECES) (31)

Stock: rubber, 100; S, 5; ZnO, 1; diphenylguanidine, 0.25; vulcanized 90 min at 148°

Softener	%	Uncured stock		Cured stock		
		Plasticity*	Softness†	$E_{60}$	$T_B$	$E_B$
None		6.05	1.18	797	144	936
Mineral oil, sp. gr., 0.905; $\eta$ , 951 190	0.125	5.32	1.31	784	152	921
	0.25	5.95	1.33	794	152	933
	0.5	5.75	1.38	800	150	948
	1	6.45	1.40	787	124	924
	2	6.75	1.42	797	121	912
	5	6.84	1.45	817	111	909
Vaseline	0.125	6.30	1.31	783	113	870
	0.25	6.35	1.31	801	145	900
	0.5	6.35	1.32	807	133	940
	1	6.27	1.36	817	131	941
	2	6.48	1.45	821	133	968
	5	6.60	1.48	826	116	935
Naphthalene	0.125	6.45	1.34	785	147	902
	0.25	6.45	1.36	794	135	917
	0.5	6.50	1.37	795	129	920
	1	6.69	1.38	800	127	922
	2	6.80	1.39	798	123	936
	5	6.85	1.39	814	107	920
Mineral rubber	0.125	6.20	1.31	819	144	960
	0.25	6.35	1.30	810	126	940
	0.5	6.35	1.30	806	110	910
	1	6.29	1.29	783	102	867
	2	6.55	1.31	772	98	894
	5	7.05	1.42	834	88	953
Pine tar	0.125	6.40	1.29	800	147	893
	0.25	6.47	1.33	807	128	925
	0.5	6.47	1.37	814	110	942
	1	6.55	1.37	831	110	947
	2	7.72	1.39	837	93	909
	5	7.83	1.42	902	93	972
Pine tar pitch	0.125	6.63	1.33	813	136	940
	0.25	6.63	1.35	810	135	937
	0.5	6.63	1.36	804	134	932
	1	6.25	1.39	815	114	922
	2	6.21	1.51	857	107	955
	5	6.21	1.64	933	84	1003
Rosin (colophony)	0.125	6.20	1.42	845	115	940
	0.25	5.90	1.42	824	104	926
	0.5	5.70	1.42	815	116	915
	1	6.20	1.50	852	114	954
	2	6.45	1.47	883	114	992
	5	7.10	1.56	930	82	948

TABLE 116.—EFFECT OF SOFTENERS ON PROPERTIES OF CURED AND UNCURED STOCK (RING-SHAPED TEST PIECES) (31).—  
(Continued)

Softener	%	Uncured stock		Cured stock		
		Plas- ticity*	Soft- ness†	$E_{60}$	$T_B$	$E_B$
Rubber resin	0.125	5.80	1.47	825	119	936
	0.25	5.80	1.47	832	115	940
	0.5	6.12	1.48	859	108	957
	1	6.60	1.51	869	109	974
	2	6.65	1.58	916	84	975
	5	6.72	1.61	962	81	1020
Rosin oil	0.125	6.05	1.39	782	147	934
	0.25	6.11	1.40	775	146	920
	0.5	6.21	1.40	770	146	911
	1	6.30	1.39	775	136	902
	2	6.35	1.48	843	119	962
	5	6.43	1.67	896	92	968
Rape oil	0.125	6.22	1.30	747	147	887
	0.25	6.26	1.30	751	146	892
	0.5	6.35	1.30	758	144	907
	1	6.35	1.39	768	102	846
	2	6.55	1.47	808	125	926
	5	6.67	1.51	834	99	911
Linseed oil (raw)	0.125	5.12	1.30	785	132	910
	0.25	5.64	1.31	784	130	908
	0.5	6.15	1.30	780	139	905
	1	6.22	1.37	826	116	935
	2	6.55	1.42	789	115	898
	5	6.57	1.51	845	102	933
Olive oil	0.125	6.45	1.30	811	118	911
	0.25	6.70	1.33	828	113	922
	0.5	6.80	1.40	851	103	939
	1	7.10	1.44	853	123	972
	2	6.96	1.51	854	110	953
	5	6.60	1.60	868	104	962
Stearin	0.125	5.57	1.40	732	126	855
	0.25	5.57	1.40	739	131	865
	0.5	5.57	1.40	750	145	894
	1	5.60	1.43	770	144	930
	2	5.85	1.41	755	131	890
	5	7.02	1.40	790	130	930
Palm oil	0.125	6.25	1.42	798	142	939
	0.25	6.20	1.44	815	131	940
	0.5	6.23	1.44	824	128	949
	1	6.35	1.47	784	140	924
	2	6.66	1.51	815	107	906
	5	6.70	1.66	863	113	970
Oleic acid	0.125	6.35	1.38	865	119	963
	0.25	6.35	1.40	843	112	950
	0.5	6.40	1.44	846	108	943
	1	6.44	1.46	872	106	940
	2	6.95	1.56	827	98	1017
	5	8.12	1.82	1020	84	1080
Stearic acid	0.125	5.25	1.40	824	123	941
	0.25	5.35	1.44	827	126	950
	0.5	5.50	1.46	833	117	958
	1	6.30	1.53	858	126	989
	2	6.73	1.55	902	118	1030
	5	7.60	1.56	954	111	997

TABLE 116.—EFFECT OF SOFTENERS ON PROPERTIES OF CURED AND UNCURED STOCK (RING-SHAPED TEST PIECES) (31).—  
(Continued)

Softener	%	Uncured stock		Cured stock		
		Plas- ticity*	Soft- ness†	$E_{60}$	$T_B$	$E_B$
Palmitic acid	0.125	6.45	1.40	783	129	910
	0.25	6.50	1.44	790	131	924
	0.5	6.55	1.48	800	137	930
	1	6.55	1.50	842	137	982
	2	6.60	1.58	919	104	1030
	5	6.70	1.63	954	105	1070
Ceresin wax	0.125	5.94	1.39	811	144	951
	0.25	6.07	1.40	802	144	940
	0.5	6.05	1.41	794	146	936
	1	6.27	1.46	815	142	952
	2	6.55	1.48	813	130	942
	5	7.08	1.44	820	118	933
Carnauba wax	0.125	5.17	1.46	864	117	977
	0.25	4.25	1.48	859	114	914
	0.5	4.44	1.51	830	114	977
	1	4.18	1.40	866	133	993
	2	3.80	1.48	855	114	977
	5	3.66	1.33	855	110	969

\* Depression (mm) in 3 min in Williams' plastometer at 70° with a load of 5 kg on a disc 5 cm<sup>2</sup> in area and 1 cm thick.

† Depression (mm) with 3 mm steel ball under 0.5 kg load at room temperature.

TABLE 117.—INFLUENCE OF FATTY OILS ON TENSILE PROPERTIES OF PURE GUM VULCANIZATE (122)

Stock: rubber, 90; S, 10; vulcanized at 143.3°

Cottonseed oil		Time of cure, hr				
		1.5	2	2.5	3	3.5
$T_5$ (kg)	without oil . . . . .	3.7	5.25	6.5	8.5	10.9
	with 2 % oil . . . . .	3.15	4.2	6.1	7.6	9.7
$T_B$ (kg)	without oil . . . . .	19.1	25.1	25.8	30.0	33.8
	with 2 % oil . . . . .	9.6	18.8	24.2	20.4	18.0
$E_B$	without oil . . . . .	936	877	820	769	726
	with 2 % oil . . . . .	857	896	831	730	619

Similar results with rape-seed oil, palm oil and mineral oil.

#### ACCELERATORS OF VULCANIZATION

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## ARSENIC

TABLE 118.—EFFECT OF DIFFERENT AMOUNTS OF THE ACCELERATOR (EXPRESSED AS % OF THE TOTAL MIXTURE) UPON THE TIME OF OPTIMUM CURE FOR SLAB AND CREPE (52)  
 Stock: rubber, 90; S, 10; vulcanized at 140° (ring-shaped test pieces)

As <sub>2</sub> O <sub>3</sub>	Cure, min		As <sub>2</sub> O <sub>3</sub>	Cure, min		As <sub>2</sub> O <sub>3</sub>	Cure, min	
	Slab	Crepe		Slab	Crepe		Slab	Crepe
0	45	120	0	75	150	0	45	120
0.0002	40	105	0.4	37	60	0.0021	35	95
0.0096	40	95	0.8	35	77	0.1050	34	75
0.0192	45	95	3.2	40	105	0.315	40	115
			6.4	90	165	0.660	80	180

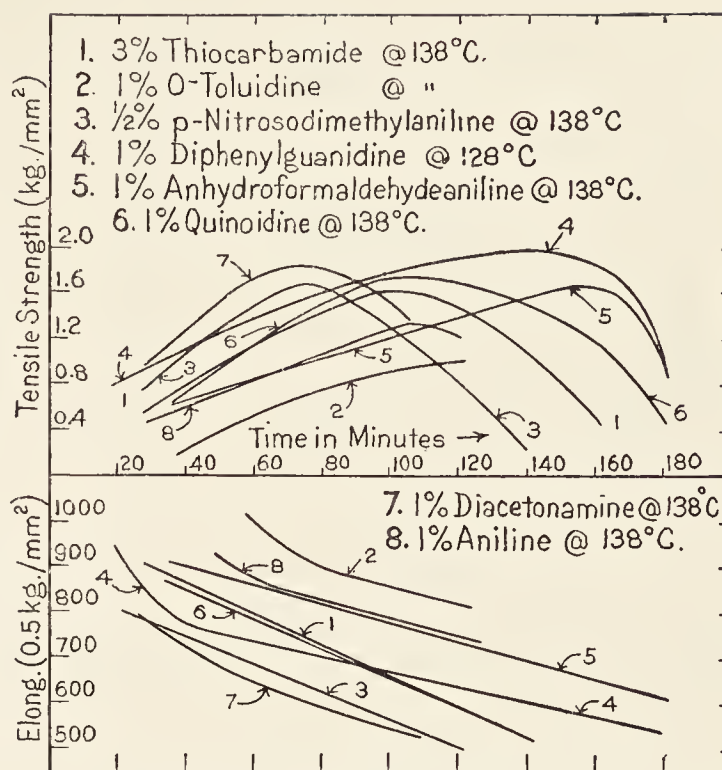


FIG. 57.—Various accelerators in the absence of ZnO. Basal stock: rubber, 90; S, 10. Tensile strength and stiffness (ring-shaped test pieces) (170).

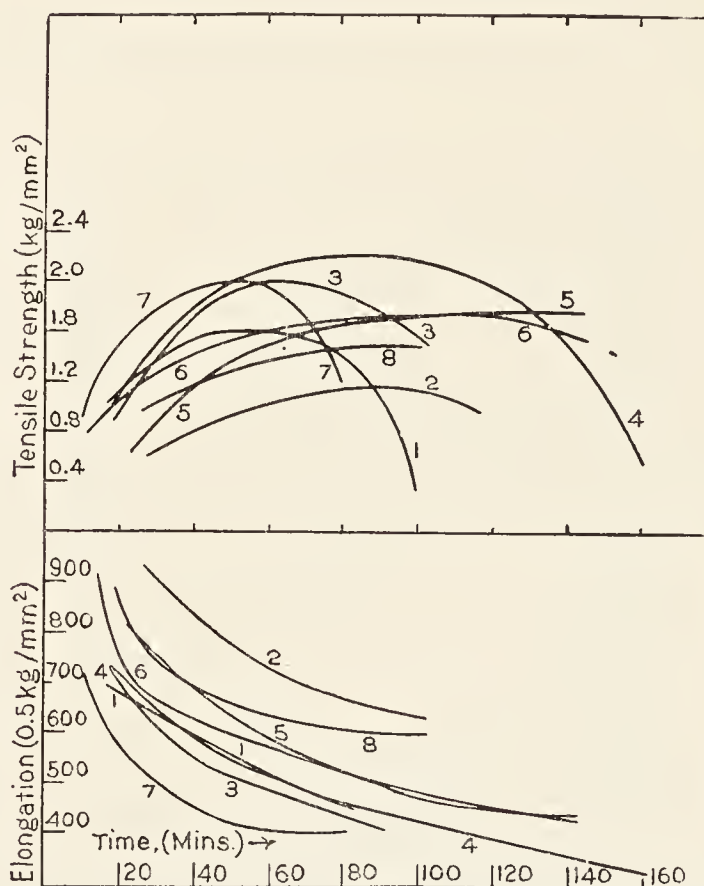


FIG. 58.—Various accelerators in the presence of ZnO. Basal stock: rubber, 90; S, 10; ZnO, 5. Tensile strength and stiffness (ring-shaped test pieces) (170). For key to numbers see Fig. 57.

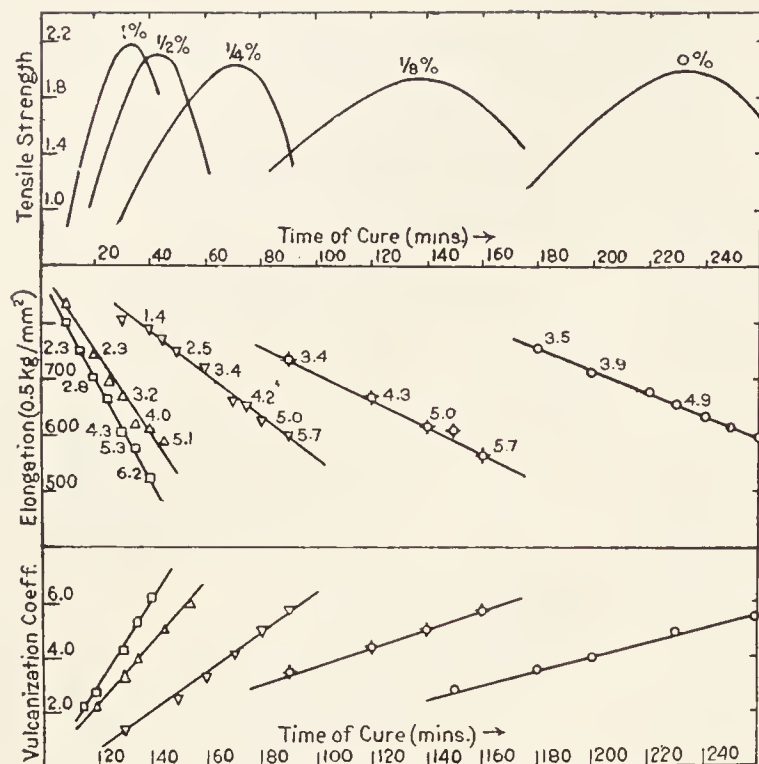


FIG. 59.—Influence of various proportions of aldehyde ammonia at 138° on rate of vulcanization, ultimate tensile strength, stiffness, vulcanization coefficient and flatness of curve. Basal stock: rubber, 90; S, 10 (ring-shaped test pieces) (165). Data are also given for vulcanization of the same mixture at 98°, 108°, 118°, and 148°. Temperature coefficient for these mixtures, see Table 70. ZnO has little or no effect on the activity of aldehyde ammonia (165).

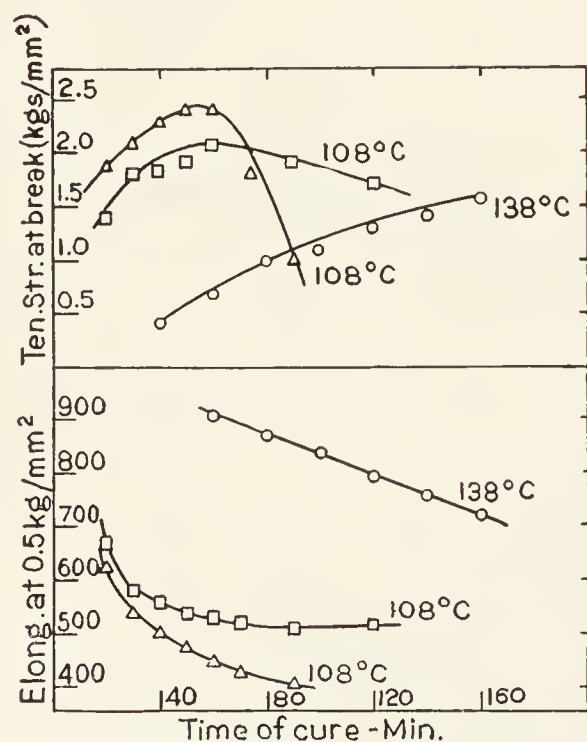


FIG. 60.—Zinc dimethyldithiocarbamate (0.25 part) when employed with and without ZnO (ring-shaped test pieces) (166). ○—rubber, 90; S, 10. □—rubber, 90; S, 10; ZnO, 1. △—rubber, 90; S, 10; ZnO, 5.

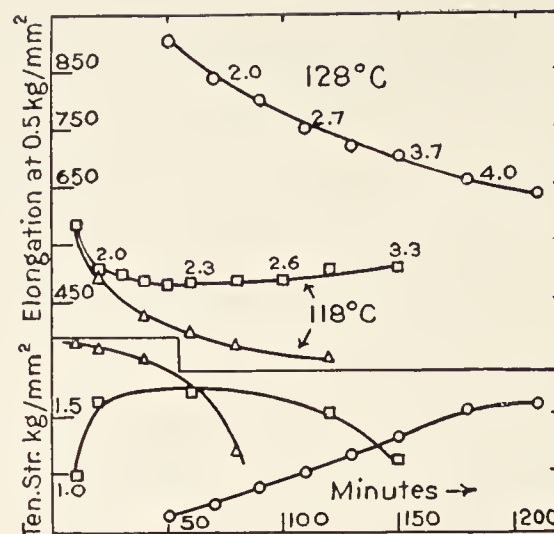


FIG. 61.—Piperidinium pentamethylenedithiocarbamate (0.25 part) with and without ZnO (ring-shaped test pieces) (162). ○—rubber, 90; S, 10. □—rubber, 90; S, 10; ZnO, 1. △—rubber, 90; S, 10; ZnO, 5. Vulcanization coefficients insert for curves ○ and □

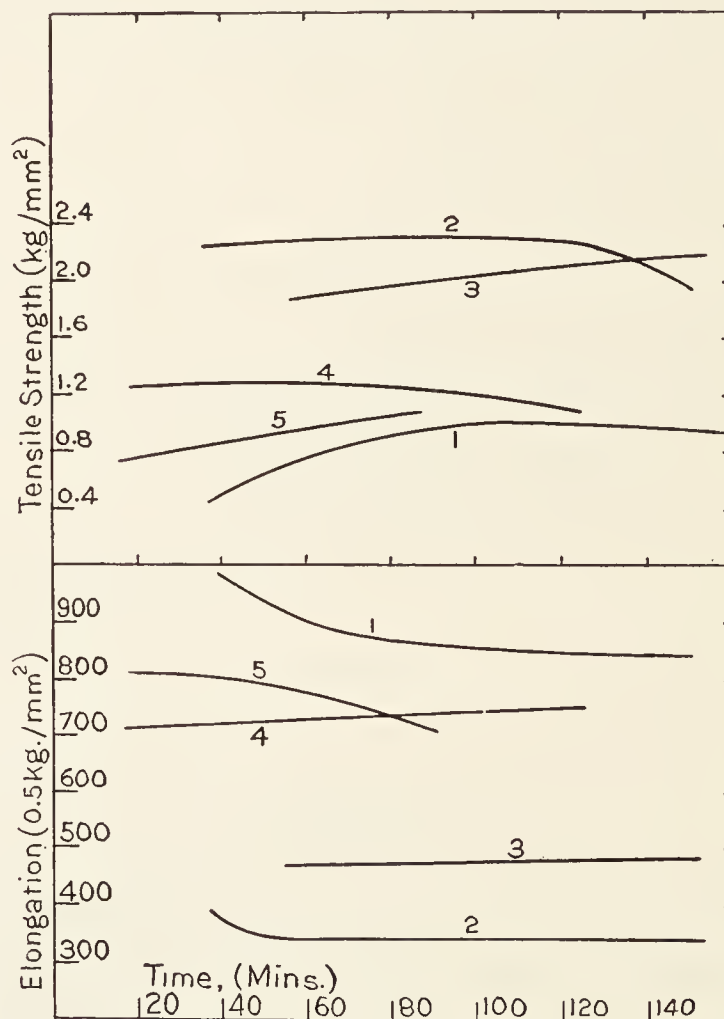


FIG. 62.—Dixanthogen (thiocarbethoxydisulfide)—influence of temperature and of proportion of ZnO. Tensile strength and stiffness (ring-shaped test pieces) (170). (1) 2.5 % dixanthogen, 1 % ZnO, 5 % S, 128°. (2) 2.5 % dixanthogen, 25 % ZnO, 5 % S, 98°. (3) 2.5 % dixanthogen, 25 % ZnO, 5 % S, 128°. Zinc methylxanthate—influence of temperature. (4–5). 3 % zinc methylxanthate, 1 % ZnO, 10 % S at 98° and 138° (170).



## PIPERIDINIUM PENTAMETHYLENEDITHIOCARBAMATE

TABLE 119.—EFFECT OF CONCENTRATION OF ACCELERATOR IN A LOW SULFUR MIXTURE (135)

Stock: rubber, 100; S, 2; ZnO, 2.5; vulcanized at 141° (ring-shaped test pieces)

Accelerator added in admixture with 3 parts of colloidal clay. These periods for vulcanization include those giving the maximum tensile strength.

Accelerator	5 min cure			7.5 min cure			10 min cure		
	$E_{60}$	$T_B$	$E_B$	$E_{60}$	$T_B$	$E_B$	$E_{60}$	$T_B$	$E_B$
0.25	773	128	1040	775	109	1008	743	98	934
0.50	600	172	870	585	144	817	534	115	800
0.75	612	176	902	583	186	870	579	217	894
1.0	516			510	256	830	523	182	794

TABLE 120.—EFFECT OF CONCENTRATION OF ACCELERATOR IN A HIGH SULFUR MIXTURE (220)

Stock: rubber, 100; S, 7.5; ZnO, 5; vulcanized at 115° (straight test pieces)

Accelerator	20 min cure			30 min cure			40 min cure			60 min cure		
	$T_6$	$T_B$	$E_B$	$T_6$	$T_B$	$E_B$	$T_6$	$T_B$	$E_B$	$T_6$	$T_B$	$E_B$
0.25	57	215	805	133	307	740				137	302	745
0.33	66	234	815				134	324	760	164	335	730
0.50	159	325	715				247	336	650	280	298	615
0.66	230	321	660									
				267	590		215	515		194	370	

TABLE 121.—EFFECT OF CONCENTRATION OF ZnO ON THE ACTIVITY OF PIPERIDINIUM PENTAMETHYLENEDITHIOCARBAMATE (166)

Stock: rubber, 90; S, 10; accelerator, 0.25 (ring-shaped test pieces)

ZnO parts	Vulcanized at	Cure giving maximum tensile strength			
		Time, min	$E_{50}$	$T_B$	V. C.
1	118°	60	487	172	2.3
5	118°	10	587	214	
		20	504	210	1.6
20	118°	20	453	223	1.7
20	108°	30	454	219	

TABLE 122.—COMPARISON OF THE EFFECTS OF PIPERIDINIUM PENTAMETHYLENEDITHIOCARBAMATE (A) WITH ZINC PENTAMETHYLENEDITHIOCARBAMATE (B) AND ZINC PHENYL-METHYLDITHIOCARBAMATE (C) (220)

Stock: rubber, 100; S, 10; ZnO, 5; accelerator, 0.50 A or equivalent amounts B and C (straight test pieces)

Min	With accelerators; vulcanized at 115°									Control; vulcanized at 141°			
	A			B			C			Min	$T_6$	$T_B$	$E_B$
10	93	272	750	47	180	825	44	172	810	60	16	37	820
20	198	326	700	96	254	755	71	226	765	90	22	74	865
30	244	289	610							120	28	101	830
40	262	256	595	144	274	715	121	276	735	150	32	114	800
60		199	500	168	253	670	131	260	720	180	41	131	790
90		64	285	180	205	615	129	252	710	240		61	560
120							134	247	700	300		17	300

## ETHYLIDINEANILINE AND ZINC MERCAPTO-BENZOTHAZOLE

TABLE 123 (123)

A = ethylidineaniline; B = zinc mercaptobenzothiazole; cure giving maximum tensile strength; vulcanized at 141.7° (straight test pieces).

Stock, parts			Accelerator		Cure, min	$T_7$	$T_B$
Rubber	S	ZnO	A	B			
100	3	5	0.5		40	ca. 95	ca. 200
100	4	5		0.6	30	ca. 90	ca. 200

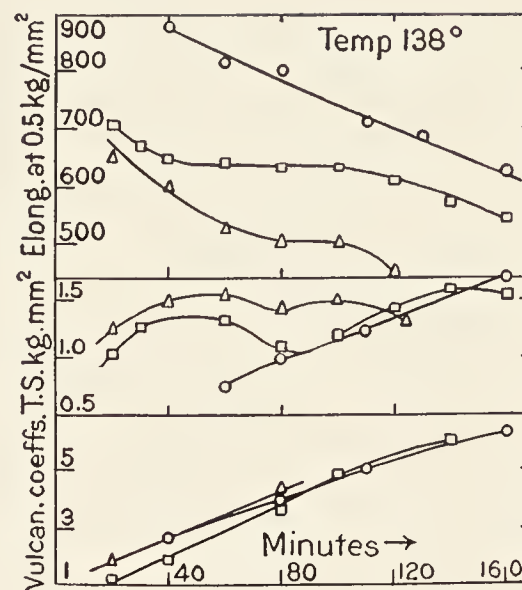


FIG. 63.—Furfuralamide (ring-shaped test pieces) (162). ○—rubber, 90; S, 10; furfuralamide, 1. □—rubber, 90; S, 10; furfuralamide, 1; ZnO, 1. △—rubber, 90; S, 10; furfuralamide, 1; ZnO, 5.

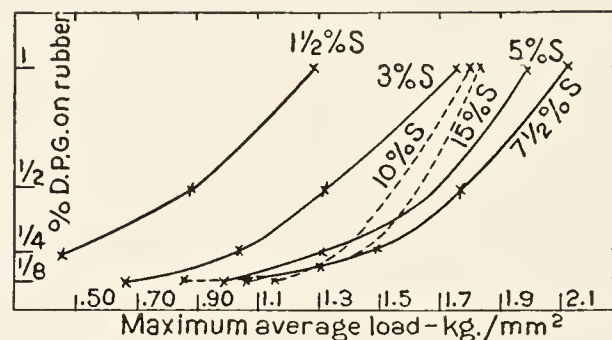


FIG. 64.—Diphenylguanidine with various proportions of S—maximum tensile strength attained. Basal stock: rubber, 100; ZnO, 5; vulcanized at 135° (ring-shaped test pieces) (4).

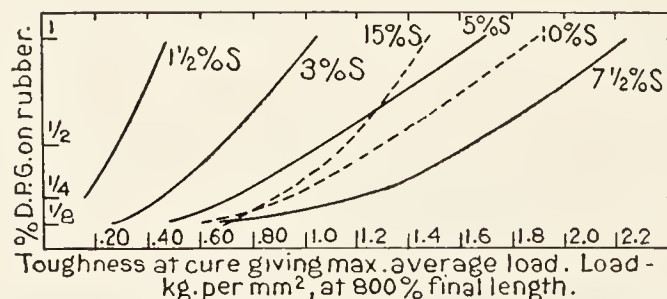


FIG. 65.—Diphenylguanidine with various proportions of S—maximum stiffness attained. Basal stock: rubber, 100; ZnO, 5; vulcanized at 135° (ring-shaped test pieces) (4).

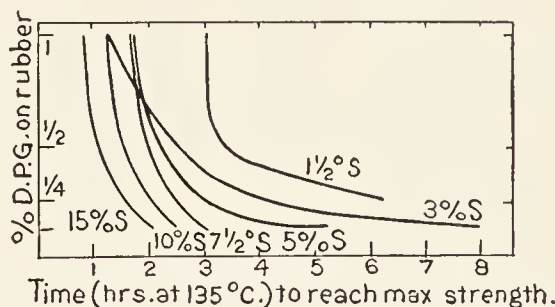


FIG. 66.—Diphenylguanidine with various proportions of S—rate of cure. Basal stock: rubber, 100; ZnO, 5; vulcanized at 135° (ring-shaped test pieces) (4).

DIPHENYLGUANIDINE

TABLE 124.—EFFECT OF ZnO AND “LIGHT” MgCO<sub>3</sub> ON THE ACTION OF DIPHENYLGUANIDINE (4)

Cure showing maximum tensile strength; vulcanized at 135° (ring-shaped test pieces)

Accelerator parts	ZnO	MgCO <sub>3</sub>	Cure, min	T <sub>B</sub>	E <sub>B</sub>	T <sub>7</sub>
Stock: rubber, 100; S, 7.5						
1	5		90	213	687	131
1	30		105	190	677	138
1	5	15	75	210	594	216
0.125	5		180	106	823	36
0.125	30		270	97	761	44
0.125	5	15	195	160	762	81
Stock: rubber, 100; S, 3						
1	5		75	176	822	48
1	30		150	175	735	93
1	5		120	206	665	159
0.125	5	15	480	66	890	16
0.125	30		540	89	792	23
0.125	5	15	420	51	704	31

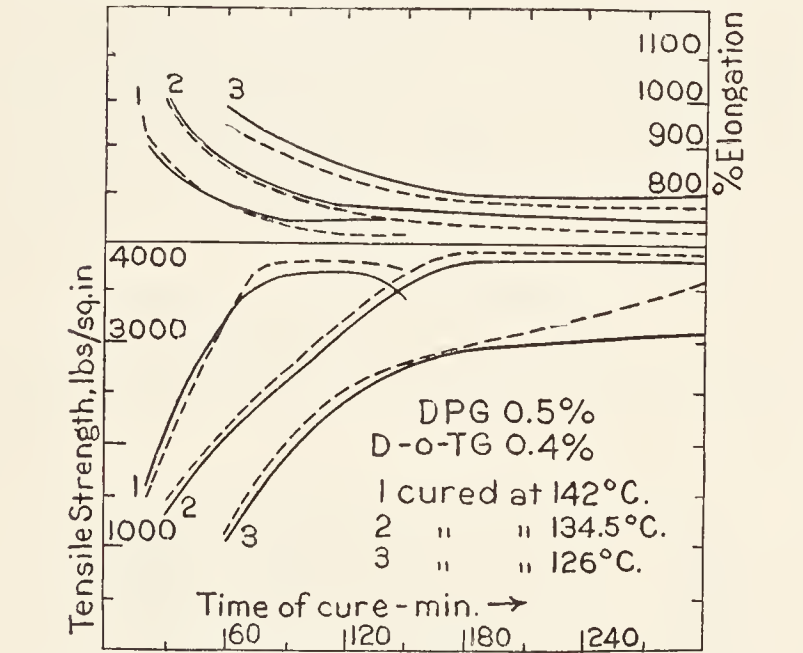


FIG. 67.—Diphenylguanidine (DPG) and Di-*o*-tolylguanidine (D-*o*-TG)—influence of temperature. Basal stock: rubber, 100; S, 4; ZnO, 3 (straight test pieces) (142).

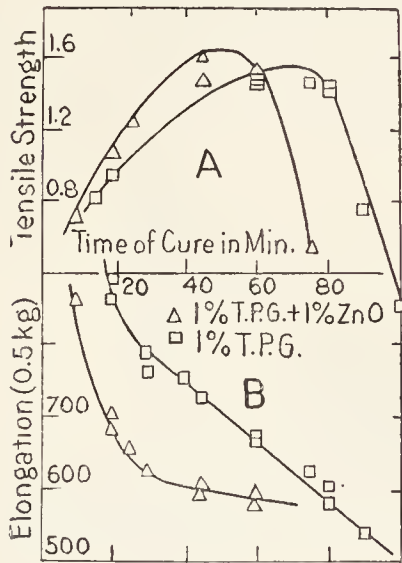


FIG. 70.—Triphenylguanidine —rate of cure as indicated by (A) tensile strength and (B) stiffness. Basal stock: rubber, 90; S, 10; vulcanized at 148° (ring-shaped test pieces) (167).

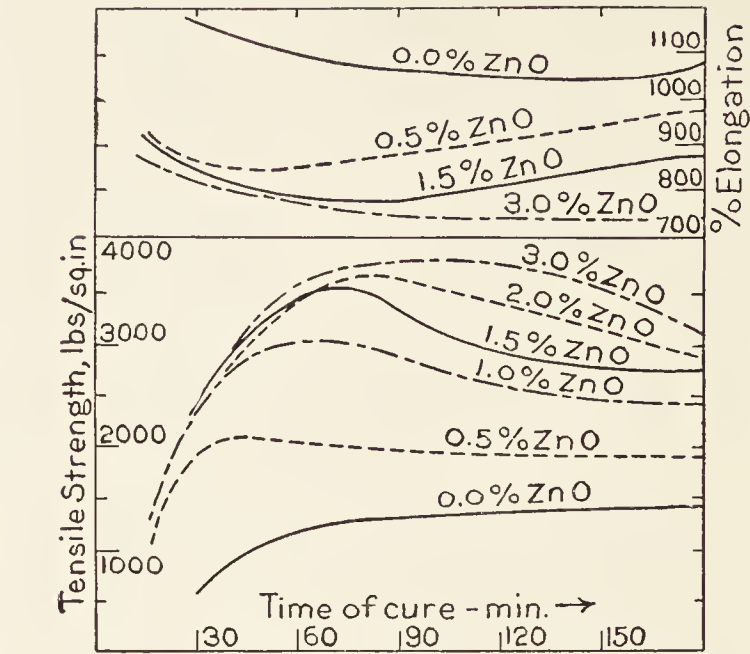


FIG. 68.—Di-*o*-tolylguanidine—influence of various proportions of ZnO on accelerating power. Basal stock: rubber, 100; S, 3; di-*o*-tolylguanidine, 0.5; vulcanized at 141° (straight test pieces) (142).

HEXAMETHYLENETETRAMINE

TABLE 125.—EFFECT OF THE ACCELERATOR IN THE PRESENCE OF GREAT QUANTITIES OF ZnO (226)

Stock: rubber, 100; ZnO, 100; S, 7 (straight test pieces)

Cure, min	% hexamethylenetetramine									
	0		0.5		0.75		1.0		1.5	
	T <sub>B</sub>	E <sub>B</sub>	T <sub>B</sub>	E <sub>B</sub>	T <sub>B</sub>	E <sub>B</sub>	T <sub>B</sub>	E <sub>B</sub>	T <sub>B</sub>	E <sub>B</sub>
Vulcanized at 141.7°										
45			102	510	140	540				
60			140	550	163	520	152	520	147	480
90			148	490			188	480	158	420
120	82	680	146	480			197	470	198	410
150	87	550			183	460	140	340	119	300
180	88	500			205	460				
210	87	500								
Vulcanized at 147.8°										
30							119	540	152	500
45			154	520	154	510	180	500	186	450
60	82	500	160	500	172	520	176	500	180	440
90	93	500	188	490	188	480	163	420	103	270
120			159	470	159	410				
150	122	540								
180	116	530								
Vulcanized at 152.8°										
20									172	510
30							134	520	188	520
45			172	480	182	480	192	490	180	420
60	99	480	200	500	191	470	186	480	152	380
90	113	500	113	330	103	300	160	240		
120	122	540								
150	88	470								

LITHARGE

TABLE 126.—INFLUENCE OF SMALL QUANTITIES OF LITHARGE (156)  
Stock: rubber, 90; S, 10; vulcanized 60 min at 138° (ring-shaped test pieces)

% PbO....	0	0.1	0.25	0.5	0.8
T <sub>8</sub> .....	23.7	24.4	24.8	28.2	37.0
V. C....	1.26	1.25	1.27	1.37	1.75



## MAGNESIUM OXIDE

TABLE 127.—INFLUENCE OF SMALL QUANTITIES OF MAGNESIUM OXIDE (156)

Stock: rubber, 90; S, 10; vulcanized 60 min at 138° (ring-shaped test pieces)

% MgO .....	0	0.1	0.25	0.4	0.75
$T_8$ .....	15.2	39.0	75.5	112.0	132.0
V. C. ....	1.40	2.66	3.31	3.68	4.08

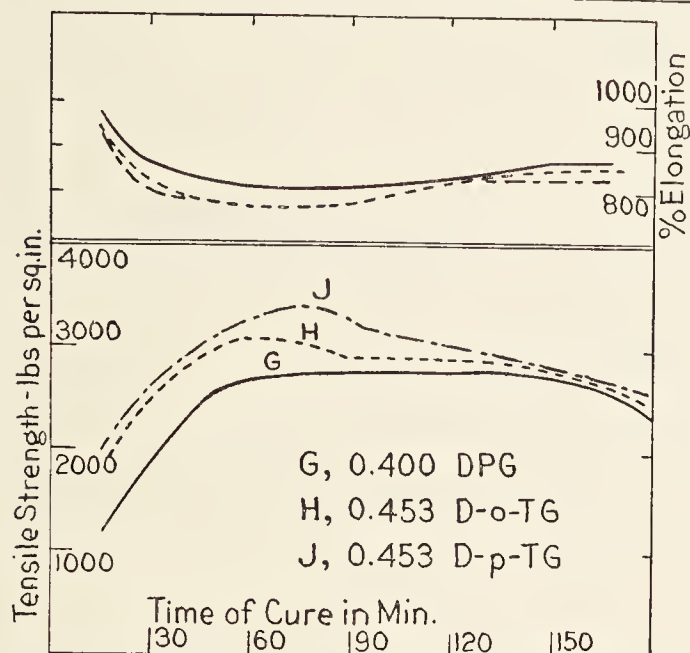


FIG. 69.—Comparison of the activity of equimolecular amounts of diphenyl-, di-o-tolyl- and di-p-tolylguanidine. Basal stock: rubber, 100; S, 4; ZnO, 1; vulcanized at 141° (straight test pieces) (142).

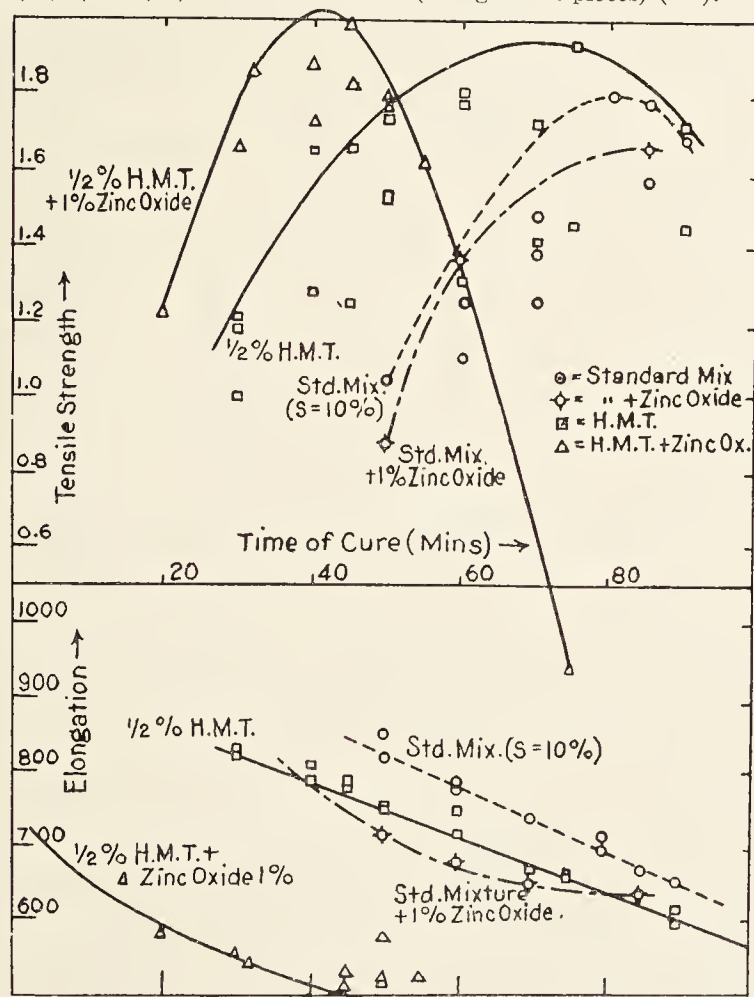


FIG. 71.—Hexamethylenetetramine (HMT) with and without zinc oxide. Basal stock: rubber, 90; S, 10 (ring-shaped test pieces) (165).

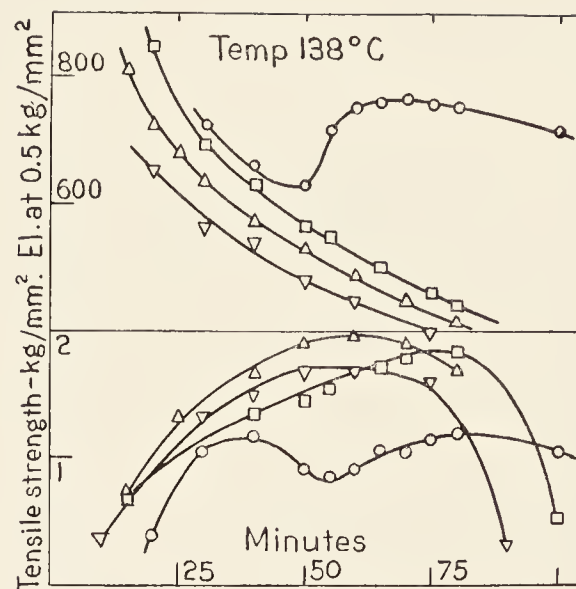
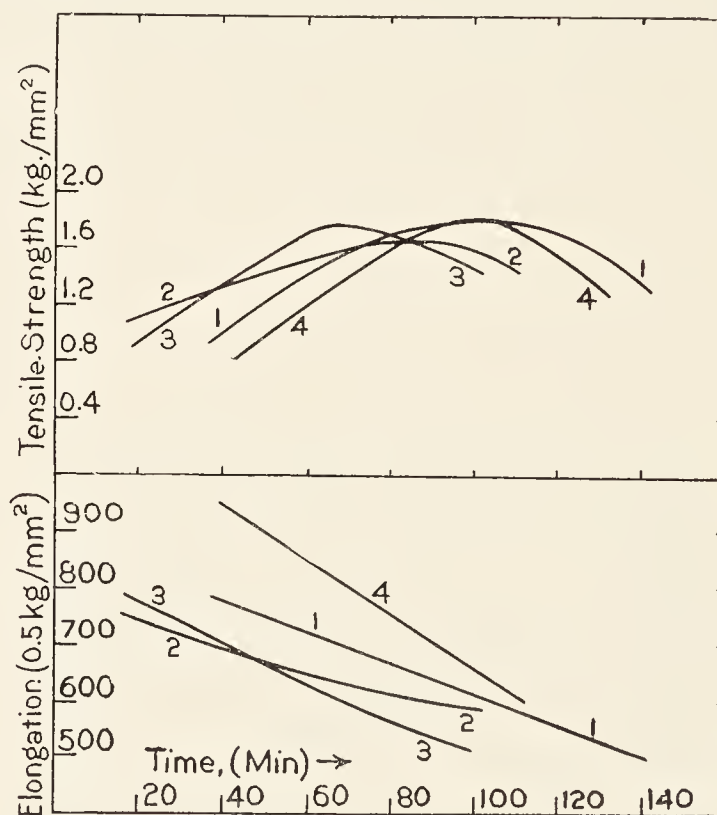


FIG. 72.—Hexamethylenetetramine (HMT) and zinc oxide. Tensile strength and stiffness (ring-shaped test pieces) (162). ○—rubber, 90; S, 10; ZnO, 0.5; HMT, 1. □—rubber, 90; S, 10; ZnO, 2; HMT, 1. △—rubber, 90; S, 10; ZnO, 5; HMT, 1. ▽—rubber, 90; S, 10; ZnO, 5; HMT, 2.5.

FIG. 73.—Basal stock: rubber, 90; S, 10. Tensile strength and stiffness (ring-shaped test pieces) (170). (1) Sodium phenoxide (1%) at 138°. (2) Zinc sulfate ammonia ( $\text{ZnSO}_4 \cdot 5\text{NH}_3$ ) (Sulzin) (1%) at 138°. (3) Lime (5%) at 138°. (4) Rubber, 90; S, 10 at 148°.*p*-NITROSODIMETHYLANILINETABLE 128.—INFLUENCE OF ZnO AND MgO ON THE ACTION OF *p*-NITROSODIMETHYLANILINE (4); cf. FIGS. 57, 58

Stock: rubber, 100; S, 10; accelerator, 0.5; ZnO or MgO, 5; vulcanized at 142° (ring-shaped test pieces)

ZnO				MgO			
Cure, min	$T_6$	$T_B$	$E_B$	Cure, min	$T_6$	$T_B$	$E_B$
20	31	133	875	15	24	90	886
30	35	103	804	25	41	166	890
50		24	465	35	44	135	834

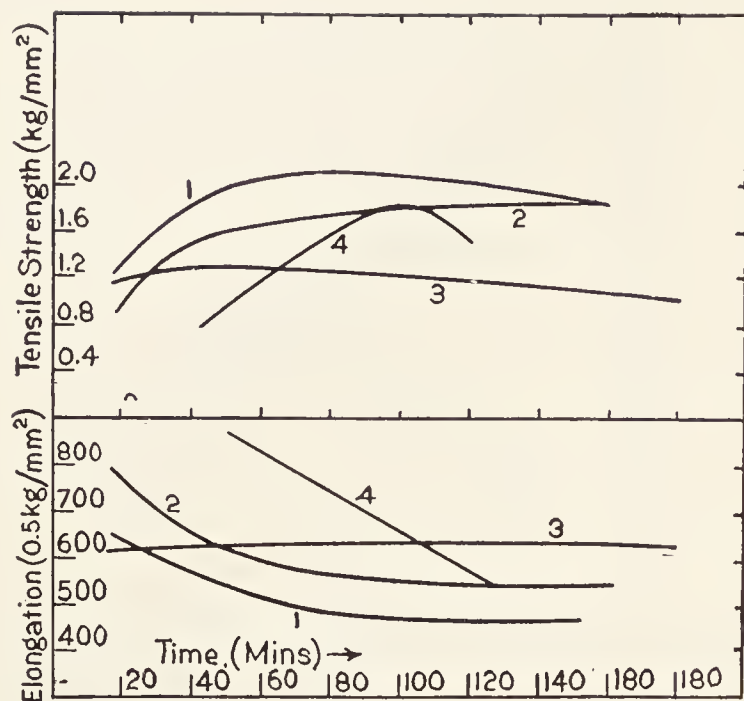


FIG. 74.—Basal stock: rubber, 90; S, 10. Tensile strength and stiffness (ring-shaped test pieces) (170). (1) Litharge (PbO) (20 %) at 128°. (2) PbO (10 %), ZnO (5 %) at 128°. (3) Mercuric oxide (HgO) (10 %) at 128°. (4) Rubber, 90; S, 10 at 148°.

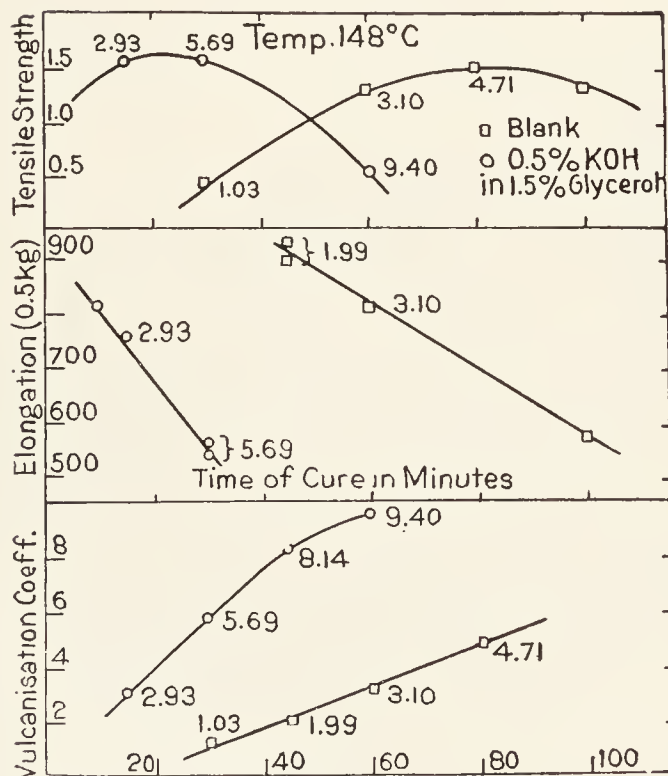


FIG. 77.—Potassium hydroxide. Tensile strength and stiffness (ring-shaped test pieces) (vulcanization coefficients inserted) (167). Basal stock: rubber, 90; S, 10. ZnO has little or no influence on the accelerating activity of KOH in rubber mixtures (220).

#### TETRAMETHYLTHIURAM DISULFIDE

TABLE 129.—VULCANIZATION WITH TETRAMETHYLTHIURAM DISULFIDE; NO SULFUR ADDED (166)

Stock: rubber, 90; ZnO, 5; accelerator, 5 (ring-shaped test pieces)

$t$ , °C	Cure, min	$E_{50}$	$T_B$
148	15	580	112
138	15	695	106

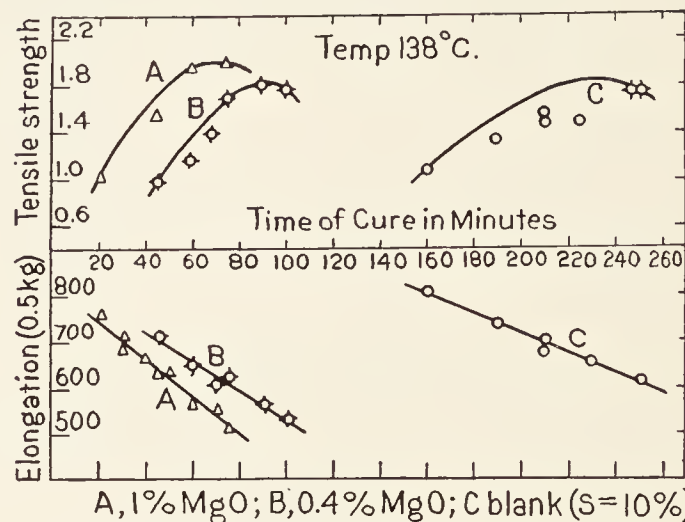


FIG. 75.—Magnesium oxide. Basal stock: rubber, 90; S, 10 (ring-shaped test pieces) (167).

#### ZINC XANTHATES

TABLE 130.—EFFECT OF ZINC ETHYLXANTHATE AND ZnO ON THE PROPERTIES OF THE VULCANIZATES AT OPTIMUM CURE (169)

Ring-shaped test pieces

$t$ , °C	Parts of		$T_B$	$E_{50}$
	Accelerator	ZnO		
Stock: rubber, 90; S, 10				
108	1	0	71	852
108	0.5	1	85	761
108	0.5	5	120	665
Stock: rubber, 95; S, 5				
108	1	1	130	641
98	3	1	169	523
98	5	1	219	486
98	5	5	214	443
98	5	20	156	403
98*	10	1	177	441
98*	10	5	189	364
98*	10	20	163	292

\* Badly over-vulcanized.

TABLE 131.—EFFECT OF ZINC ETHYLXANTHATE AND S ON THE PROPERTIES OF THE VULCANIZATES AT OPTIMUM CURE (VULCANIZATION TEMPERATURE, 108°) (169)

Ring-shaped test pieces

Rubber	S	Parts/100 parts rubber + S		$E_{50}$	$T_B$	V. C.
		Accelerator	ZnO			
100	1.0	3	1	727	122	0.5
100	3.1	3	1	612	140	1.6
100	5.3	3	1	531	171	2.5
100	11.1	3	1	486	173	3.5
100	3.1	1	1	753	97	0.7
100	5.3	1	1	652	136	1.6



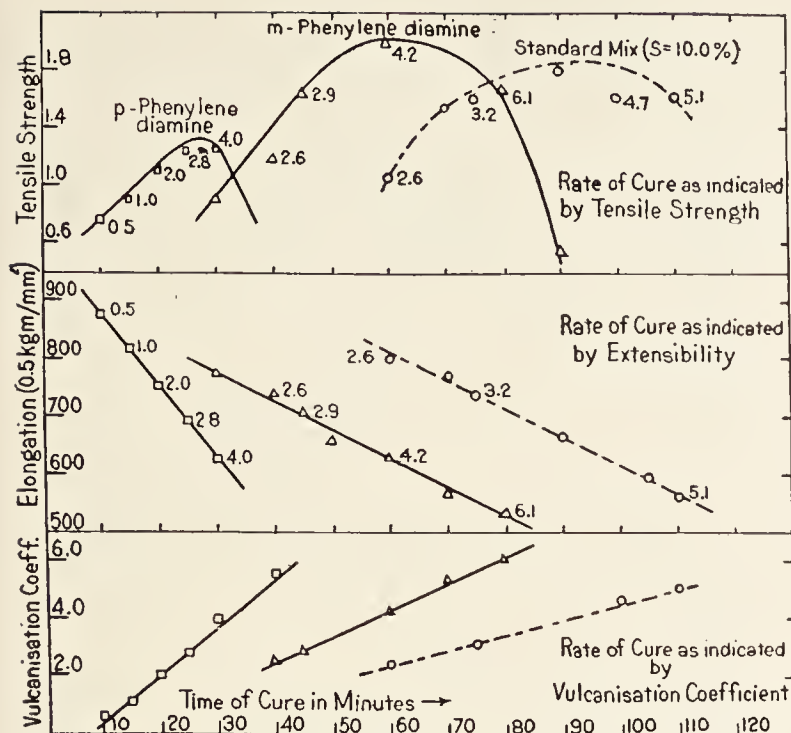


FIG. 76.—*m*- and *p*-Phenylenediamines (ring-shaped test pieces) (165). Basal stock: rubber, 90; S, 10.

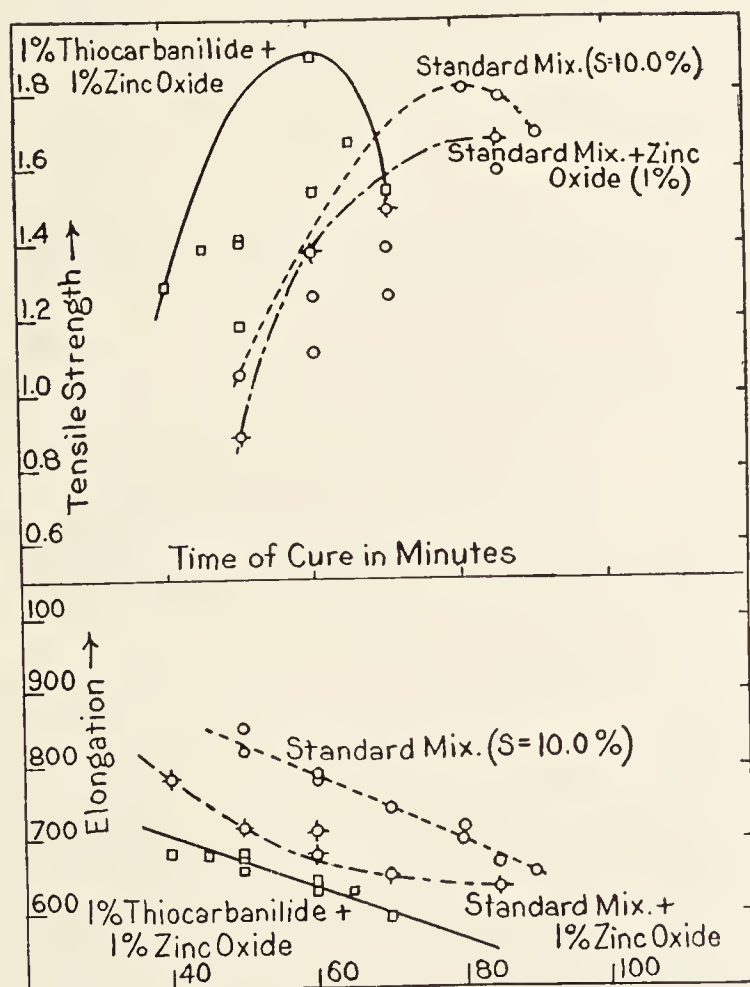


FIG. 78.—Thiocarbanilide (ring-shaped test pieces) (165). Basal stock: rubber, 90; S, 10. The "elongation" shown is the extension under a load of 0.5 kg/cm<sup>2</sup>.

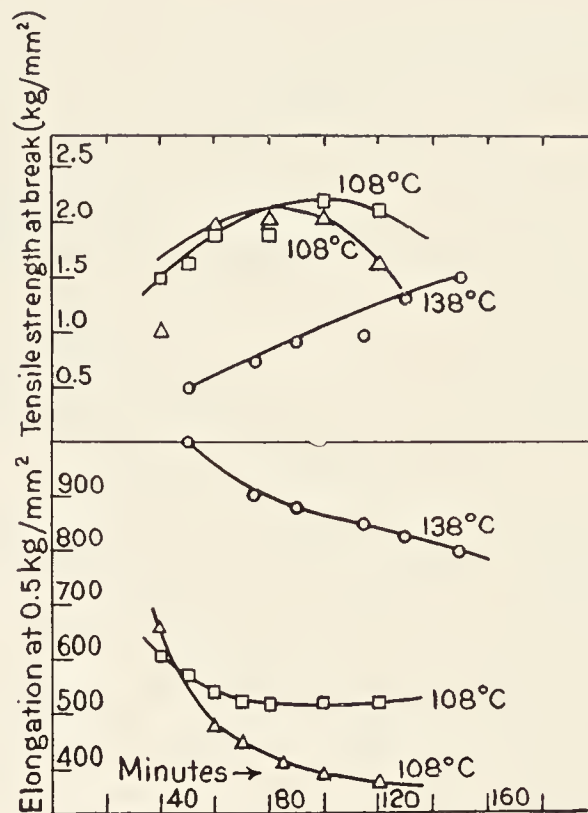


FIG. 79.—Tetramethylthiuram disulfide with and without ZnO. Tensile strength and stiffness (ring-shaped test pieces) (166). ○—rubber, 90; S, 10, tetramethylthiuram disulfide, 0.25. □—same + ZnO, 1. △—same + ZnO, 5.

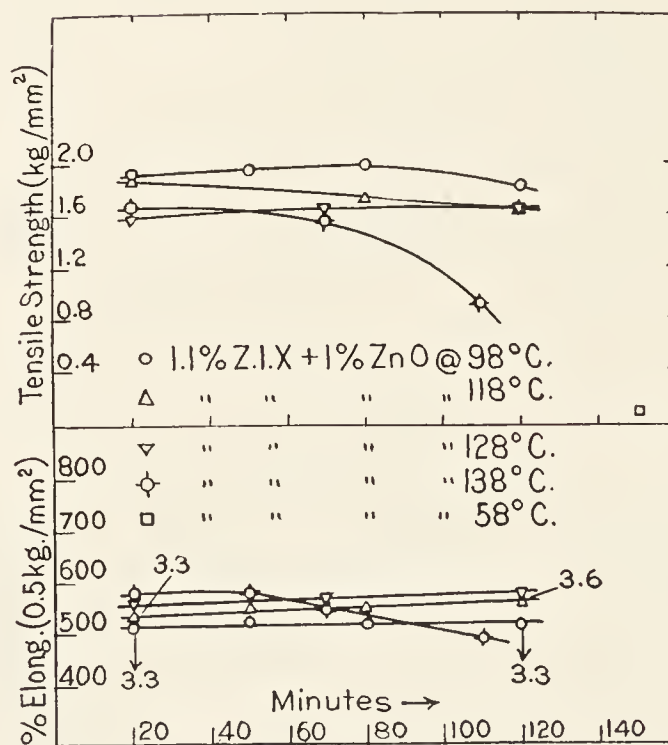


FIG. 80.—Zinc isopropylxanthate—influence of temperature and flat or static curing qualities. Tensile strength and stiffness. Basal stock: rubber, 90; S, 10. Figures inserted show vulcanization coefficients (ring-shaped test pieces) (169).

TABLE 132.—COMPARISON OF THE EFFECT OF VARIOUS ZINC XANTHATES AND INFLUENCE OF TEMPERATURE ON THEIR ACTIVITY (170)

Stock: rubber, 90; S, 10; ZnO, 1; data for optimum cures (ring-shaped test pieces)

Accelerator	Parts	Vulcanizing temperatures							
		138°		128°		118°		98°	
		<i>E</i> <sub>50</sub>	<i>T<sub>B</sub></i>	<i>E</i> <sub>50</sub>	<i>T<sub>B</sub></i>	<i>E</i> <sub>50</sub>	<i>T<sub>B</sub></i>	<i>E</i> <sub>50</sub>	<i>T<sub>B</sub></i>
Zinc isopropylxanthate.....	1.1	577	168	558	167	536	190	508	200
Zinc <i>n</i> -butylxanthate.....	1.2	631	154	600	168	580	175	543	199
Zinc <i>n</i> -propylxanthate.....	1.1	706	92	666	134	642	141	606	174
Zinc methylxanthate.....	1.0					960	59	932	65
	3.0	813	74	776	100	750	103	713	124

Zinc ethylxanthate, at 88°: *E*<sub>50</sub> = 555; *T<sub>B</sub>* = 205 (169). At 108° (1 part): *E*<sub>50</sub> = 635; *T<sub>B</sub>* = 185 (170).

COMPOUNDING INGREDIENTS

TABLE 133.—AVERAGE SIZE OF THE PARTICLES (74)

Ingredient	Microns	Ingredient	Microns
Carbon black.....	ca. 0.15	ZnO	
Lampblack.....	0.3-0.4	American process..	0.4-0.6
Lithopone.....	0.3-0.4	French process.....	0.3-0.4
Sublimed white lead..	ca. 0.65	Barytes, silica, asbes-	
White lead.....	0.75-2	tine, whiting.....	ca. 5-10

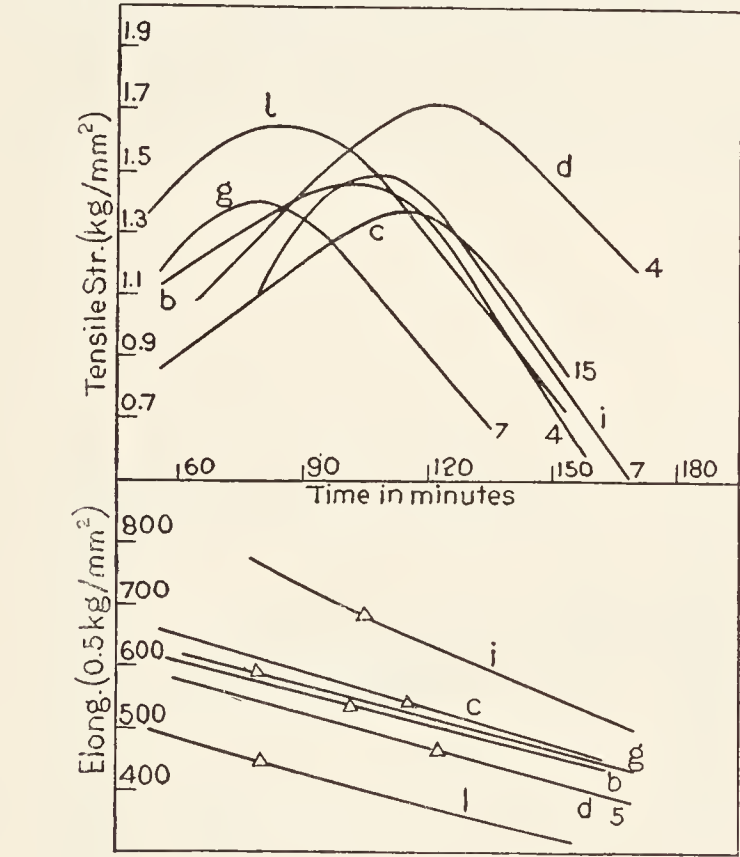


FIG. 81.

TABLE 134.—THERMAL CONDUCTIVITY (227)

For conductivity of rubber, *v. p.* 269

Compounding ingredient	Conductivity (cal/sec/cm³) (45-100°)	Compounding ingredient	Conductivity (cal/sec/cm³) (45-100°)
Antimony sulfide (15.6 % free S) ..	0.00021	MgCO <sub>3</sub> .....	0.00103
Blanc fixe.....	0.00078	Red oxide.....	0.00132
Clay (Dixie).....	0.00058	S.....	0.00012
Gas black.....	0.00067	Whiting.....	0.00084
Litharge.....	0.00051	ZnO.....	0.00166
Lithopone.....	0.00094	Cord fabric.....	0.00082*

\* Approximately.

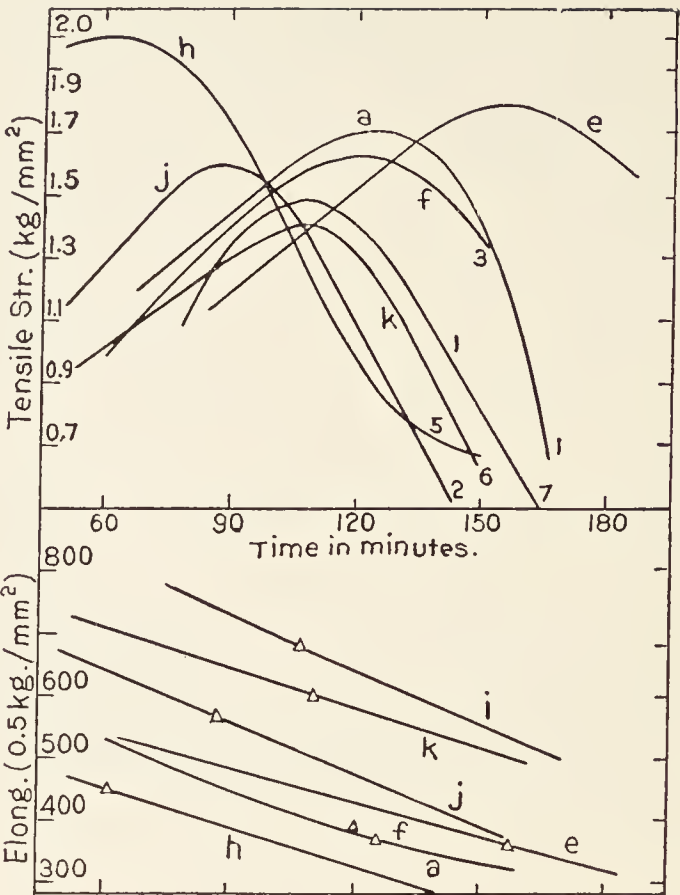


FIG. 82.

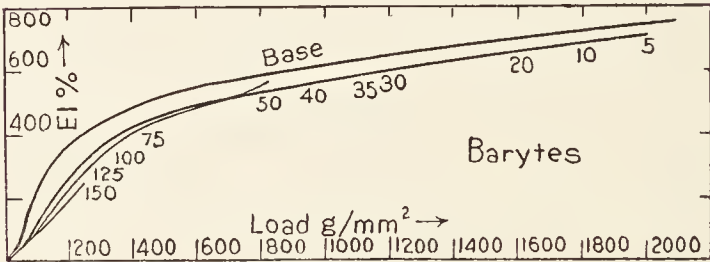


FIG. 83.

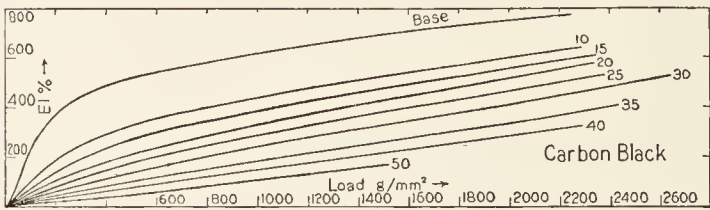


FIG. 84.

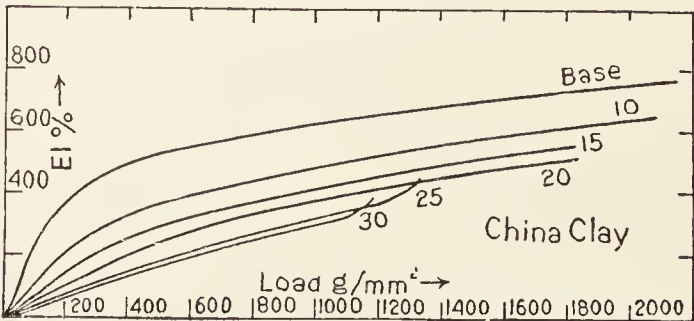


FIG. 85.



Figures 81, 82. Effect on the tensile strength, stiffness and rate of cure of an unaccelerated rubber-sulfur mixture (100:10) of 10 vols. of each of the following ingredients: (a) acetylene black; (b) pptd. barytes; (c) china clay; (d) colloidal clay; (e) gas black (carbon black); (f) lampblack; (g) lithopone; (h)  $\text{MgCO}_3$ ; (i) mineral rubber (bitumen); (j) thermatomic carbon; (k) whiting; (l)  $\text{ZnO}$  (the figures in the upper set of the curves show the number of results of which each curve represents the mean. Ring-shaped test pieces used) (168).

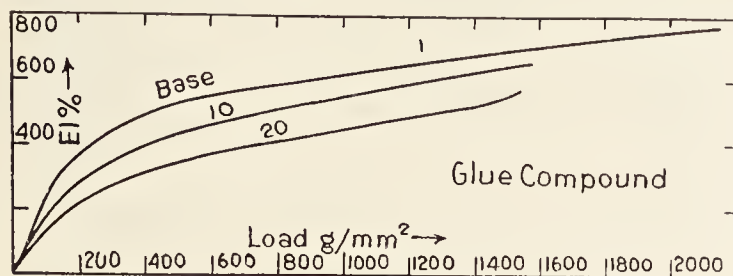


FIG. 86.

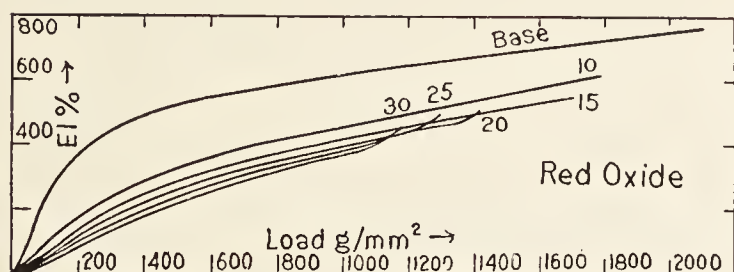


FIG. 87.

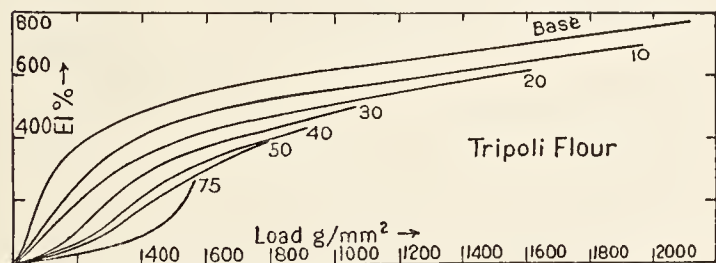


FIG. 88.

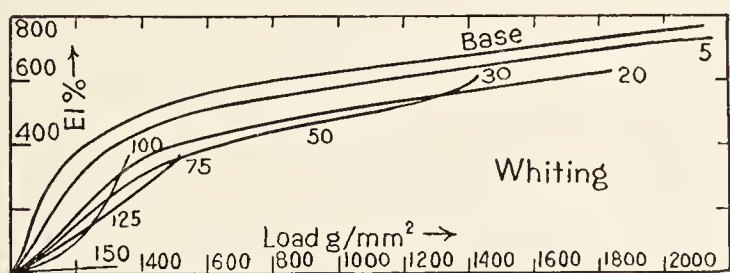


FIG. 89.

Figures 83-90. Effects on load-strain relations of various volumes of barytes (83), carbon black (84), china clay (85), glue (86), red oxide (87), tripoli flour (88), whiting (89),  $\text{ZnO}$  (90), added to the basal stock (rubber, 100;  $\text{PbO}$ , 30; S, 5. Stocks were vulcanized at  $141^\circ$  to approx. max. tensile strength) (223).

Figure 91. Effect on the load-strain relations of adding 5 vols. of barytes, carbon black, china clay, lithopone, titanium white, whiting or  $\text{ZnO}$  to the basal stock (rubber, 77.5; S, 5 vols.), vulcanized 175 min at  $141^\circ$  (ring-shaped test pieces) (104).

Figure 92. Influence on load-strain relations of various proportions of "light"  $\text{MgCO}_3$  added to the basal stock (rubber, 100;  $\text{PbO}$ , 30; S, 5; vulcanized 45 min at  $143^\circ$ ) (straight test pieces used) (75).

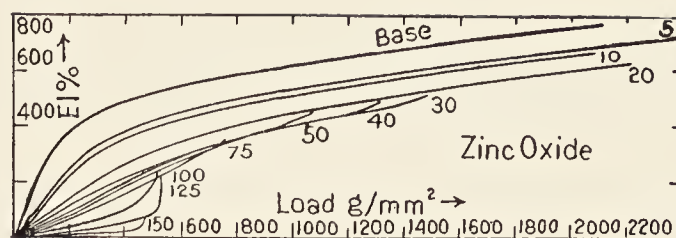


FIG. 90.

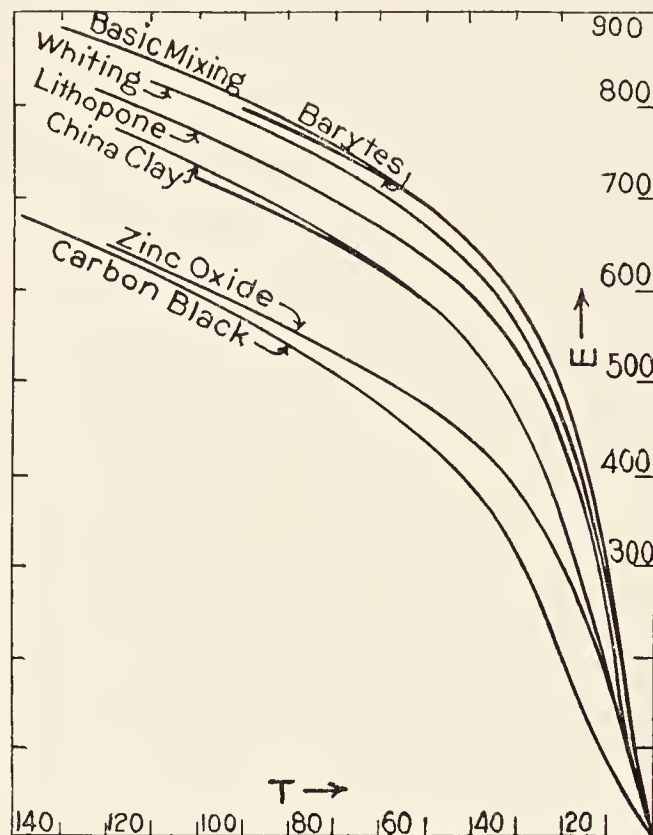


FIG. 91.

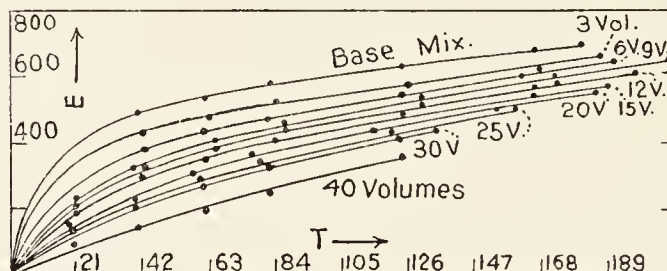


FIG. 92.

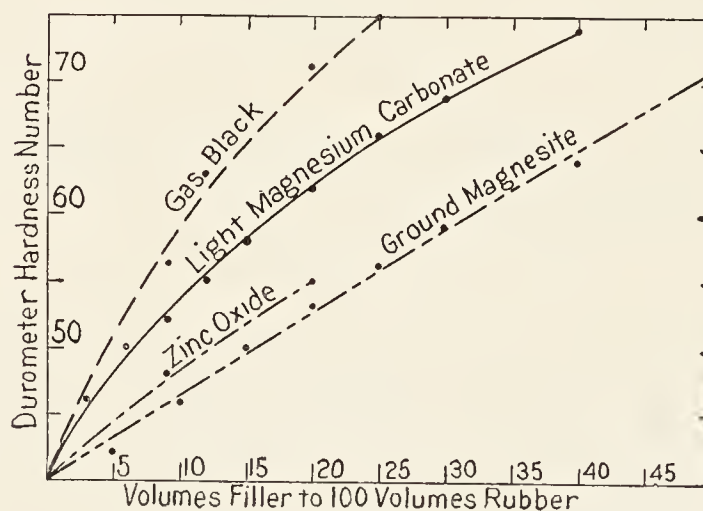


FIG. 93.

The influence of various proportions of carbon black, "light"  $\text{MgCO}_3$ , magnesite and  $\text{ZnO}$  added to the basal stock (rubber, 100;  $\text{PbO}$ , 30; S, 5; vulcanized 49 min at  $143^\circ$ ) on the hardness of rubber is shown in Fig. 93; on the sub-permanent set in Fig. 94 (75).

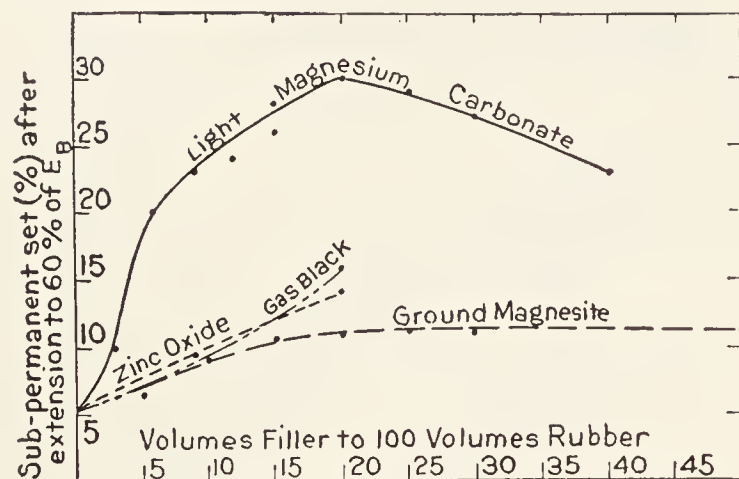


FIG. 94.

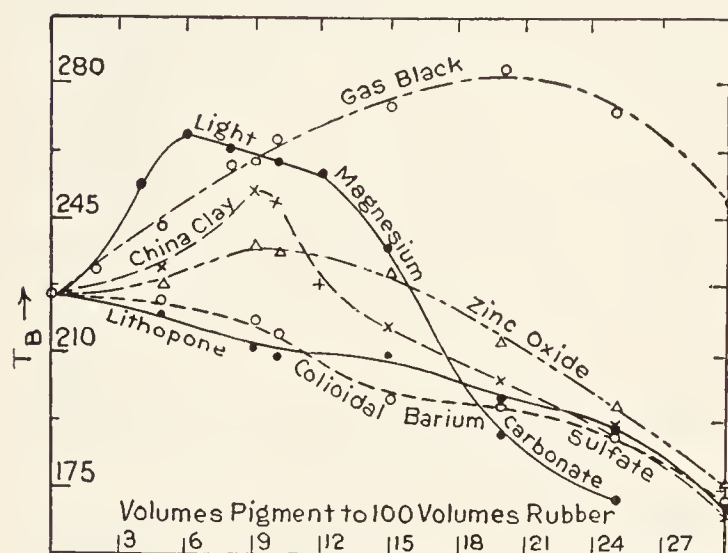


FIG. 95.

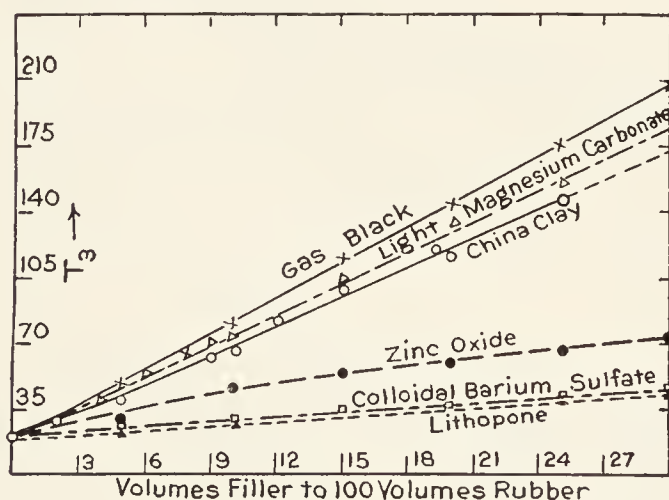


FIG. 96.

The effect of adding various proportions of  $\text{BaSO}_4$  (colloidal), carbon black, china clay,  $\text{MgCO}_3$  (light), lithopone, and  $\text{ZnO}$  to the basal stock (rubber, 100;  $\text{ZnO}$ , 5; S, 5; hexamethylenetetramine, 1; basal stock cured 80 min at  $148^\circ$ ; other stocks given a slight undercure) upon the ultimate tensile strength is shown in Fig. 95; stiffness, Fig. 96; resilient energy, Fig. 97; resistance to abrasion, Fig. 98; and hardness, Fig. 99 (straight test pieces

used). The resistance to abrasion is expressed as the percentage loss in weight of disks 5.625 cm diameter by 0.2 cm thick when rotated for 100 000 revolutions (10 hr) in loose granular carborundum (76).

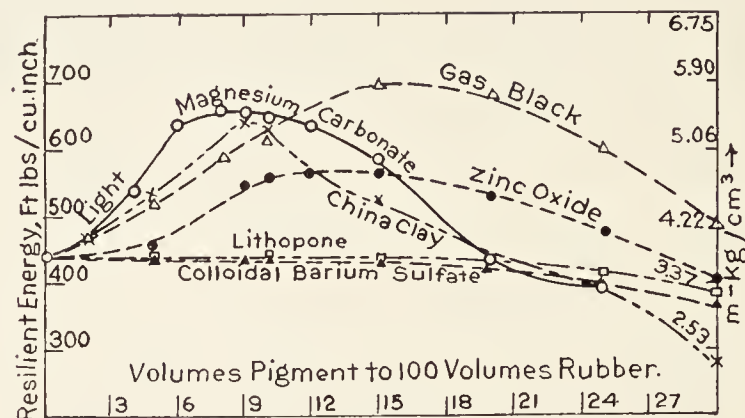


FIG. 97.

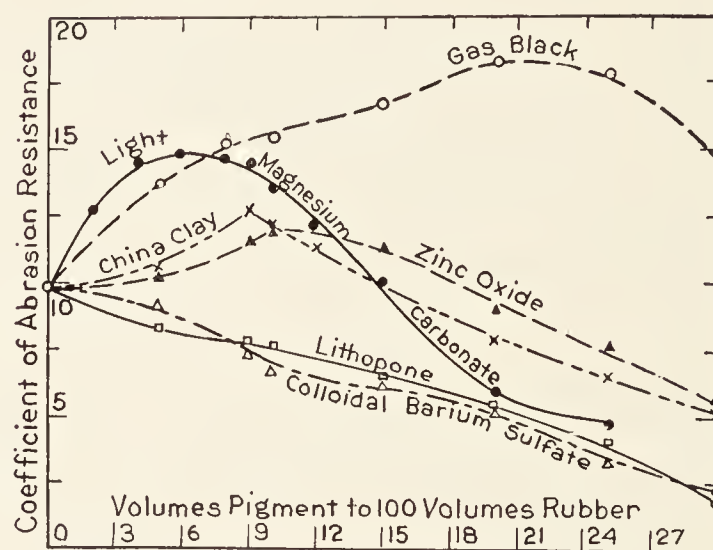


FIG. 98.

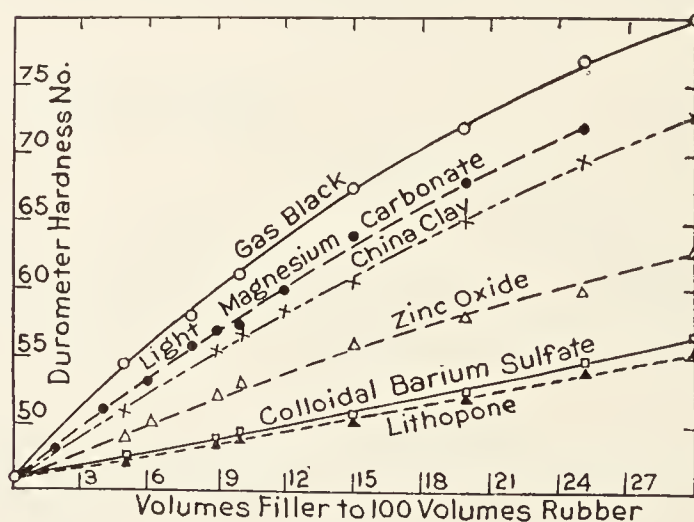


FIG. 99.

Figures 100-102 illustrate the influence on the load-strain relations, ultimate tensile strength and energy of resilience of various proportions of MR (mineral rubber, prepared from blown asphalt and gilsonite) (solid lines), and of carbon black (dotted lines) added to the basal stock (rubber, 100; S, 10) (115). Figs. 100, 102: cured at  $141^\circ$  for 165 min; Fig. 101: cures giving maximum tensile strength.



Figure 103 illustrates the influence on the sub-permanent set of various proportions of barytes, carbon black, MR and ZnO added to the basal stock (rubber, 100; S, 10) (115).

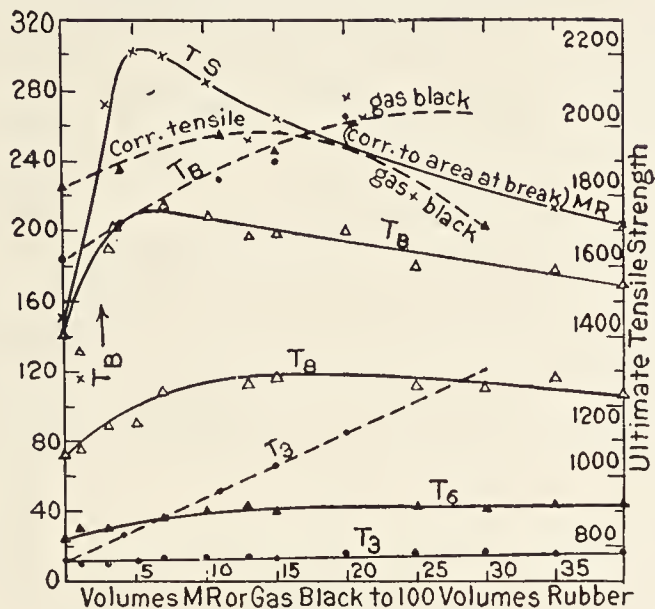


FIG. 100.

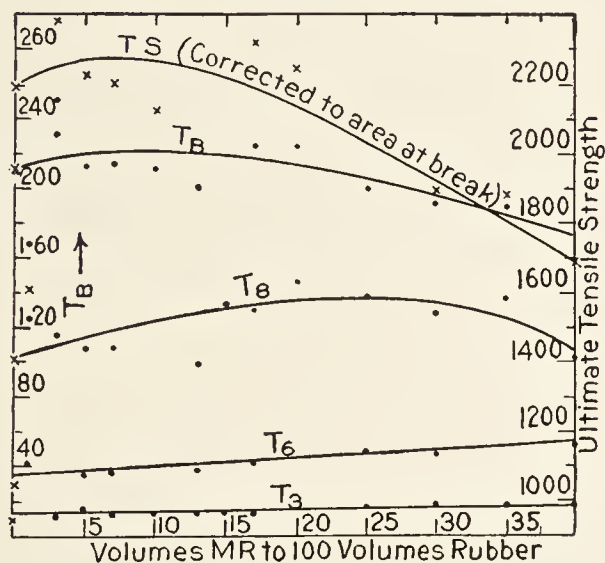


FIG. 101.

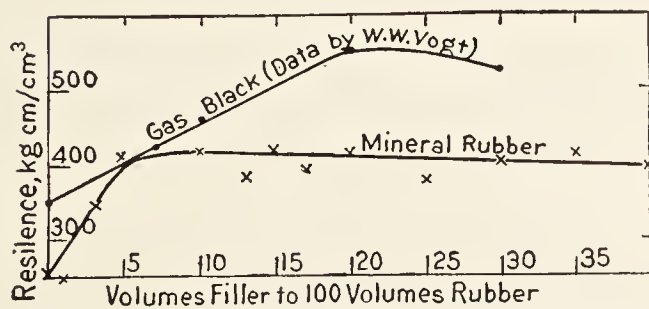


FIG. 102.

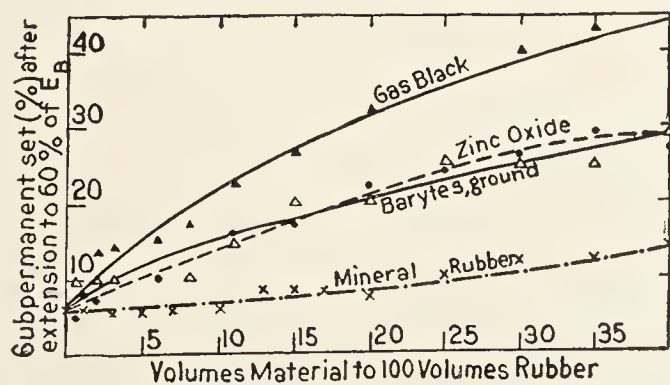


FIG. 103.

## BROWN FACTICE

Rubber substitute, vulcanized oil

TABLE 135.—EFFECT ON VULCANIZED RUBBER (4)

Stock: rubber, 100; S, 7.5; ZnO, 5; diphenylguanidine, 0.5; vulcanized 45 min at 135°

Brown factice, parts	$T_B$	$E_B$	$T_7$
0	180	748	147
1	171	746	136
5	170	738	124
10	162	791	106
40	102	698	103
40*	60	571	

\* Also contained 9 parts "light"  $MgCO_3$ ; vulcanized 60 min at 142°.

## BROWN FACTICE, "GOLDEN" ANTIMONY SULFIDE AND IRON OXIDE

TABLE 136.—EFFECT OF BROWN FACTICE WHEN USED WITH ANTIMONY SULFIDE OR IRON OXIDE (5)  
Composition of stocks

Stock	Rubber	S	Brown factice	Antimony sulfide (3% free S)	Iron oxide
A	76.5	8.0		15.5	
B	76.5	8.5			15.5
C	59.5	8.0	17.0	15.5	
D	59.5	8.5	17.0		15.0

Tensile properties after vulcanization at 141°

Stock	A		B		C		D	
Cure, min	$T_B$	$E_B$	$T_B$	$E_B$	$T_B$	$E_B$	$T_B$	$E_B$
75					89	738		
90	113	733			104	724	88	734
120	121	707			90	640	109	700
150	123	706	124	777			106	600
165			134	752				
175			136	768				
180	132	654			4	301		
190			134	731			64	514
205			134	709				
210	83	510						

## CLAY

Effect of adsorptive power (defined as % of dye adsorbed by 2 g of clay from 50 cm<sup>3</sup> of 0.1 % malachite green solution) on the properties of rubber.

TABLE 137 (159)

Stock: rubber, 48.375; clay, 21; ZnO, 11; lithopone, 17; S, 2; diphenylguanidine, 0.625; vulcanized at 145° (cure giving maximum tensile strength)

Sample No.	1	2	3	4	5	6	7
Adsorptive power, %	40.14	47.6	56.2	89.7	89.9	99.2	99.5
Cure, min	20	20	20	20	20	50	40
$T_B$	174.3	170.1	167.3	140.6	140.6	106.8	87.9

TABLE 138 (159)

Stock: rubber, 63.496; clay, 26; ZnO, 5.5; MgO, 2.0; S, 2.5; diphenylguanidine, 0.504; vulcanized at 153° (cure giving maximum tensile strength)

Sample No.	Mean size, microns	Adsorptive power, %	Cure, min	$T_B$
1	3.3	40	15	232.7
2	3.3	59	20	232
3	3.3	75	20	225

TABLE 138 (159).—(Continued)

Sample No.	Mean size, microns	Adsorptive power, %	Cure, min	$T_B$
4	5.0	75	20	214.4
5	3.2	77	20	228.2
6	3.2	81	25	208.1
7	3.9	82	20	224.3
8	3.3	82	30	220
9	2.9	85	25	200.3
10	3.7	100	40	161
11	4.4	100	40	117.4

## CARBON BLACK

TABLE 139.—EFFECT OF DIFFERENCES IN SAMPLES OF CARBON BLACK ON THE PROPERTIES OF RUBBER\* (149)

Stock A: rubber, 73.5; carbon black, 19.06; ZnO, 4.33; S, 1.84; diphenylguanidine, 1.27. Stock B: rubber, 72.83; carbon black, 18.80; ZnO, 4.25; S, 3.60; hexamethylenetetramine, 1.12.

	Cure giving maximum $T_B$					
	Stock A			Stock B		
	Mean	Max.	Min.	Mean	Max.	Min.
Cure, min.....	36	55	25	68.5	75	60
$T_B$ .....	165	244	97	154	238	85
$T_B$ .....	346	379	310	298	320	278
$E_B$ .....	703	790	604	673	737	590

\* 18 samples of carbon black were used with stock A, and 7 with stock B. For details as to their properties, v. (149).

## RECLAIMED RUBBER AS A COMPOUNDING INGREDIENT

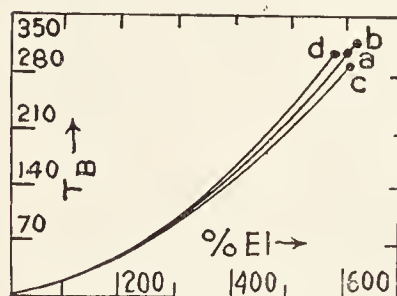


FIG. 104.

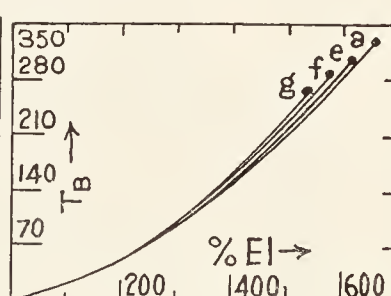


FIG. 105.

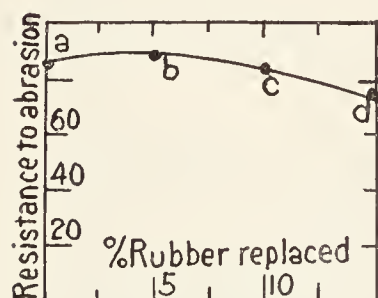


FIG. 106.

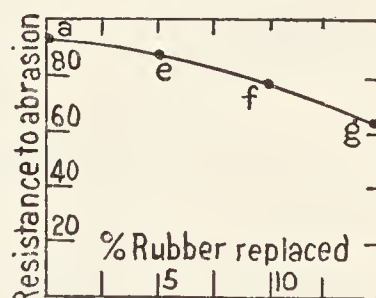


FIG. 107.

TABLE 140.—VULCANIZATION OF RECLAIMED RUBBER (16)  
Whole black tire reclaim (alkali process): sp. gr., 1.18; acetone extract, 7.5%; ash, 20%

Composition				Vulcanized at 142°		
Rubber	S	ZnO	Diphenylguanidine	Cure, min	$T_B$	$E_B$
100	5	0	0	20	54.8	410
100	5	0	0	30	59.8	450
100	3	3	0.5	20	93.5	400
100	3	3	0.5	30	80.9	320

TABLE 141.—COMPOSITION OF STOCKS CONTAINING RECLAIMED RUBBER, SHOWING POSSIBLE VARIATIONS IN THE AMOUNTS OF ZnO AND CARBON BLACK USED

For load-strain curves and resistance to abrasion, v. Figs. 104–107 (16)

Sample	Original stock*	Reclaimed rubber content increased, with decrease:					
		Of ZnO			Of carbon black		
	a	b	c	d	e	f	g
Rubber.....	60	57	54	51	57	54	51
Reclaim†.....	0	6	12	18	6	12	18
ZnO.....	12	8	4	0	13	14	15
Carbon black.....	24.1	25.1	26.1	27.1	20.1	16.1	12.1

\* Contained also: S, 2.4; ethyldineaniline, 0.45; diphenylguanidine, 0.45; stearic acid, 0.3; mineral oil, 0.3. † For properties of the reclaimed rubber, v. Table 140.

## AGING

TABLE 142.—EFFECT OF AGE ON THE VULCANIZATION OF RAW RUBBER

Stored in the tropics (53); cf. Tables 24, 144; stock: rubber, 90; S, 10

Type	Number of samples	Mean age, mo	Mean time of cure (min) at 141°		Mean tensile product ( $T_B \times E_B/1000$ )	
			Initial	After aging	Initial	After aging
Slab crepe....	23	34	76.3	106.3	129.8	100.5
Crepe.....	35	34.5	172	138	118.1	105.7
Sheet.....	27	34.5	135	120	129.1	110.8

TABLE 143.—AGING OF CEYLON BLANKET CREPE (154)

	Air-dried*		Heat-dried*	
	Initial	After 2 yr	Initial	After 2 yr
Cure, min.....	127	116	135	130
$T_B$ .....	145	141	140	132
Slope.....	34.5	35	35.5	36.5
$\eta$ , 1% in $C_6H_6$ †.....	39.5	26.5	23.5	17.5
$\eta$ , 1% in $C_6H_6 + HCl$ †.....		15		12

\* Two samples. † Viscosity relative to that of solvent.

TABLE 144.—AGING OF SLAB CREPE (205)

Stock: rubber, 92.5; S, 7.5; vulcanized at 150°; aged 4 yr in tropics

	Slab crepe	Latex crepe (control)
Number of samples.....	6	3
% $H_2O$ .....	0.41	0.34
% ash.....	0.34	0.20
% aqueous extract.....	0.45	0.28
Cure, min { initial.....	39.5	107
aged.....	57	105
$T_B$ { initial.....	146	146
aged.....	133	148
Slope { initial.....	34	36
aged.....	34	36
$\eta$ , relative { initial.....	102	39
aged.....	23	31



TABLE 145.—AGING OF PURE GUM STOCK AT ROOM TEMPERATURE\*

Influence of % of S (200)

Stock A: rubber, 90; S, 10; vulcanized 80 min at 148°

Age, da	$T_B$	$E_B$	$E_{130}$
3	129	906	907
111	142	873	853
181	136	851	842
380	135	821	816
495	149	821	790
619	137	795	784

Stock B: rubber, 92.5; S, 7.5; vulcanized 105 min at 148°

Age, da	$T_B$	$E_B$	$E_{130}$
3	134	930	923
113	144	900	877
181	144	886	863
376	136	836	827
495	137	810	800
619	115	769	793

Stock C: rubber, 95; S, 5; vulcanized at 148°

Cure, 140 min				Cure, 200 min				Cure, 300 min			
Age, da	$T_B$	$E_B$	$E_{130}$	Age, da	$T_B$	$E_B$	$E_{130}$	Age, da	$T_B$	$E_B$	$E_{130}$
3	110	987	1023	3	131	952	950	3	105	969	1019
111	126	960	967	111	143	918	898	108	116	944	970
216	129	953	954	181	139	898	883				
430	121	889	905	376	51	581		423	12	381	
550	116	869	895	457	14	380		532	10	333	
673	93	899	856	567	13	314					

\* Ca. 27° (in tropics).

TABLE 146.—ACCELERATED AGING OF PURE GUM STOCK AT 65° (180)

Influence of degree of vulcanization; stock: rubber, 92.5; S, 7.5; vulcanized at 148°

Age, da	Cure, 70 min			
	$T_B$	$E_B$	$E_{90}$	V. C.
0	86.5	1053	1115	1.98
1	75	1009	1052	
2	85	998	1010	
3	92	982	976	2.42
4	93	965	958	
6	94.5	952	943	2.30
9	95	926	912	
16	98	903	885	2.70

Age, da	Cure, 90 min				Cure, 110 min			
	$T_B$	$E_B$	$E_{130}$	V. C.	$T_B$	$E_B$	$E_{130}$	V. C.
0	91	984	1060	2.82	128.5	943	950	3.89
1	103	949	998		134	919	915	
2	110	937	973		137	901	889	
3	106	914	956	3.24	139.5	888	872	4.07
4	119	907	925		136.5	858	848	
5	129	912	924	2.96	141.5	853	835	4.02
7	125.5	900	907		143	848	825	
12	104.5	833	878	3.74	104	722		4.27

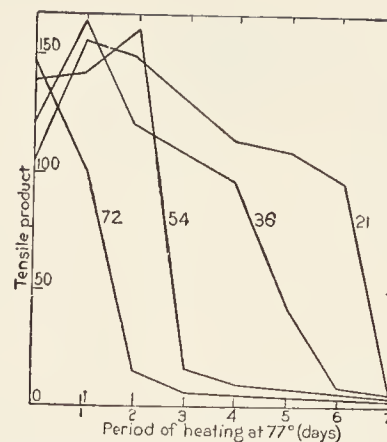


FIG. 108.—Accelerated aging of pure gum vulcanized rubber. Influence of degree of vulcanization on the tensile product of the stock. Basal stock: rubber, 100; S, 8; vulcanized at 143° (111). The figures on the curves denote the time (in min) of vulcanization at 143°.

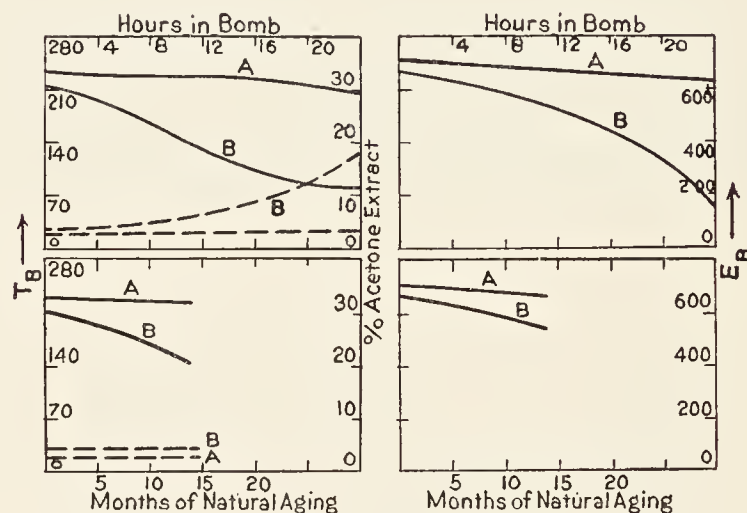
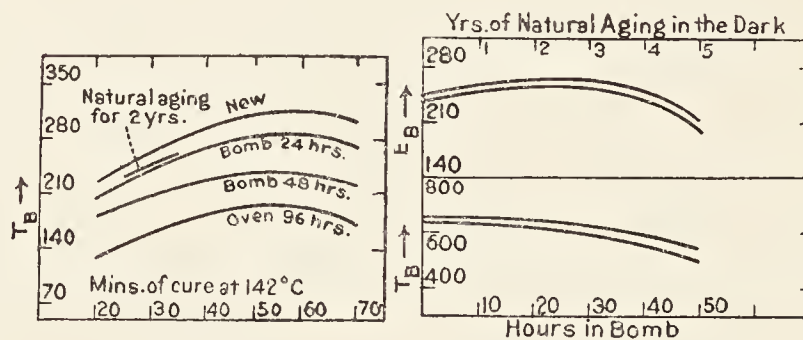
FIG. 109.—Comparison of aging of some compounded stocks in the dark at room temperature with aging accelerated by heating at 60° in oxygen at a pressure of 21 kg/cm<sup>2</sup> (straight test pieces) (15). Stock A: rubber, 100; S, 4; diphenylguanidine, 0.5; pptd. whiting, 50; ZnO, 4; vulcanized 30 min at 142°. Stock B: rubber, 100; S, 6; PbO, 10; pptd. whiting, 50; vulcanized 25 min at 142°.

FIG. 110.

FIG. 111.

FIG. 110.—Same as Fig. 109. Stock: rubber, 100; S, 1; tetramethylthiuram disulfide, 1; ZnO, 100; vulcanized 10 min at 134° (15).

FIG. 111.—Comparison of aging in the dark at room temperature, accelerated aging at 60° in oxygen at 21 kg/cm<sup>2</sup>, and accelerated aging at 70° in a current of air at atm. pressure in the case of a tire tread stock vulcanized for various periods (15). Stock: rubber, 60; S, 3; diphenylguanidine, 0.5; ethyldieneaniline, 0.375; pine tar, 1; ZnO, 17.125; carbon black, 18. For further data on the aging of compounded stocks, especially low-grade stocks, see (32).

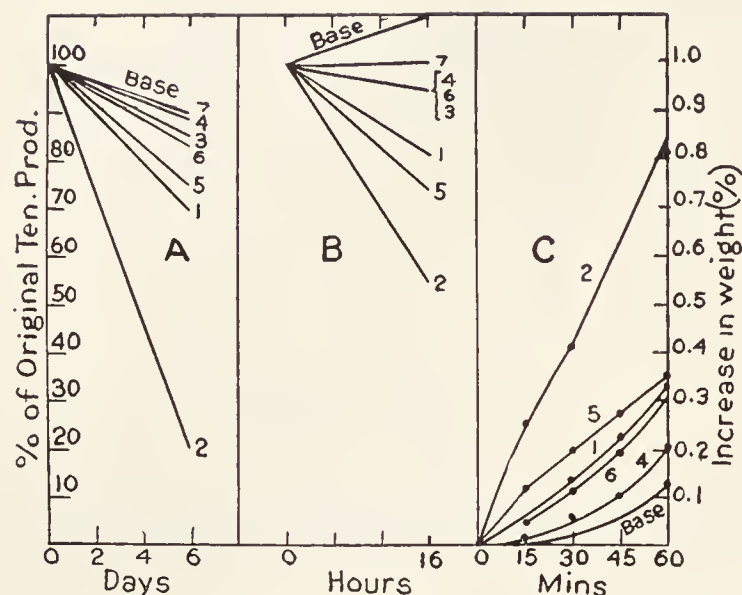


FIG. 112.—Influence of compounding ingredients on accelerated aging. Basal stock: rubber, 100; ZnO, 5; S, 4; diphenylguanidine, 0.75. Other stocks prepared by adding 20 vols. of the following to 100 vols. of rubber: (1) barytes; (2) carbon black; (3) clay; (4) MgCO<sub>3</sub>; (5) thermatonic carbon; (6) whiting; (7) ZnO (173). (A) Effect on the tensile product of heating the best technical cure (30-45 min at 141° for all stocks except 4 (15 min) and 2 (60 min)) for 6 days in a current of air at atmospheric pressure and 70°. (B) Effect on the tensile product of heating the best technical cure for 16 hr in oxygen at 28 kg/cm<sup>2</sup> and 60°. (C) Increase in weight as in (B) of the vulcanizates obtained by various periods of cure (mins denote period of vulcanization at 141°).

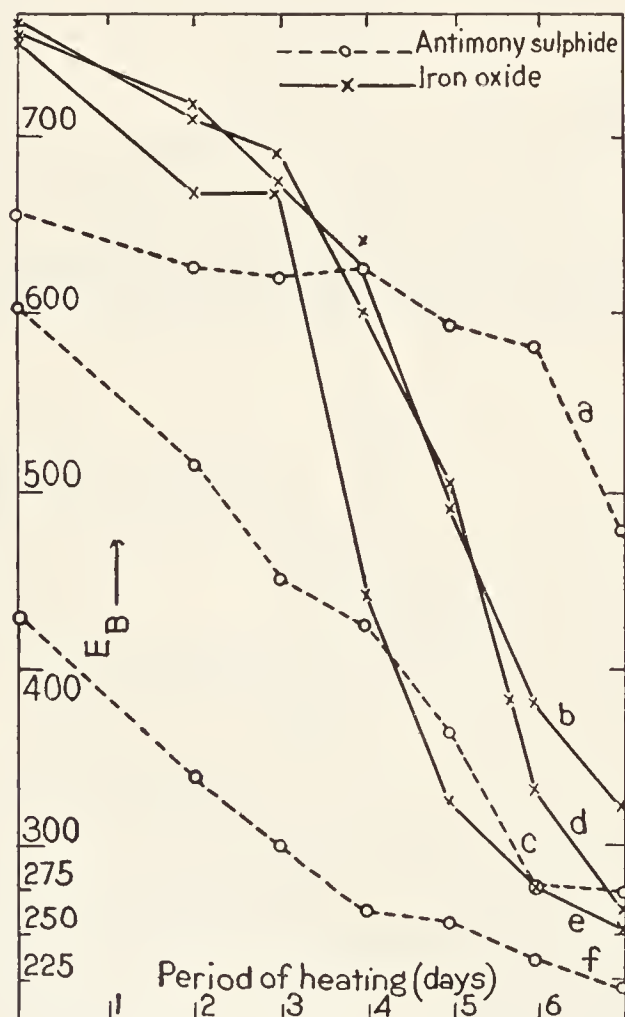


FIG. 114.—Change of ultimate elongation on aging as in Fig. 113 (5).

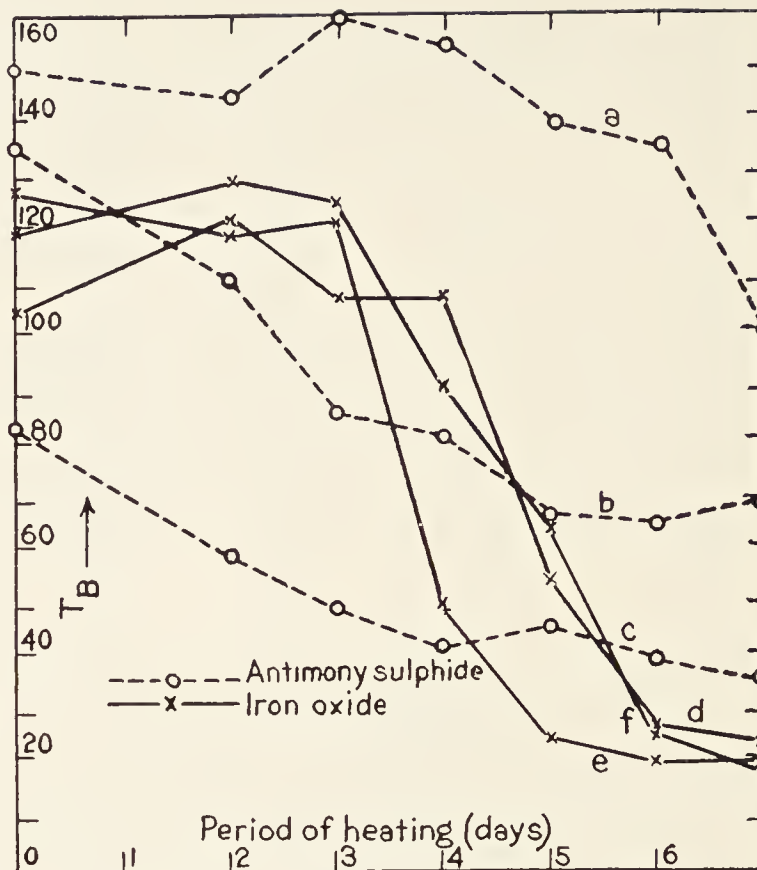


FIG. 113.—Change in tensile strength on accelerated aging at 70° in a current of air at atmospheric pressure of stocks containing (A) Fe<sub>2</sub>O<sub>3</sub>, (B) Sb<sub>2</sub>S<sub>5</sub>. Stock A: rubber, 76.5; S, 8.5; Fe<sub>2</sub>O<sub>3</sub>, 15. Stock B: rubber, 76.5; S, 8; "golden" Sb<sub>2</sub>S<sub>5</sub> (3 % free S), 15.5. Vulcanized at 141° (a), 2 hr; (b) and (d) 2.25 hr; (c) and (f), 2.5 hr; (e) 2.75 hr (5).

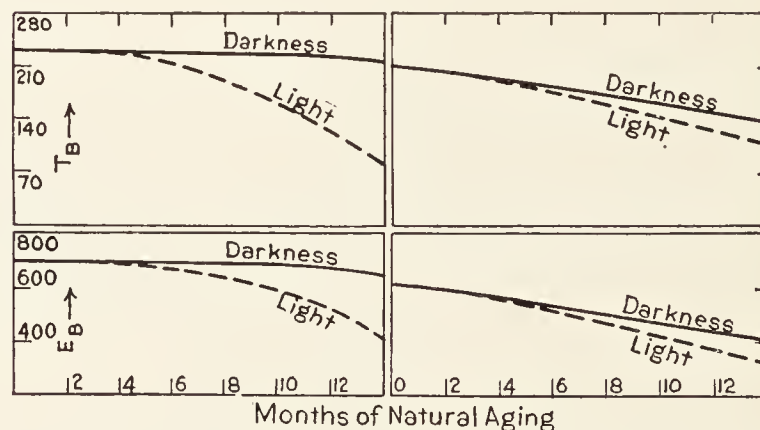


FIG. 115.—Influence of light on aging at room temperature. Curve marked "light" is for rubber behind glass in a very light room (15). Stock (left-hand curves): rubber, 100; S, 4; ZnO, 4; diphenylguanidine, 0.5; pptd. whiting, 50; (right-hand curves): rubber, 100; S, 6; litharge, 10; pptd. whiting, 50 (cf. Fig. 109).

## HARD RUBBER

**Commercial Samples.**— $T_B$  = 105-700;  $E_B$  = 2-75; compressive strength = 210-1400 kg/cm<sup>2</sup>; sp. gr. = ca. 1.20 (mean) (33).  
**Electrical Properties.**—v. Tables 105-110.  
**Coefficient of Thermal Expansion.**— $80 \times 10^{-6}$  (20-60°) (148).  
**Specific Gravity.**—v. commercial samples and Tables 105, 106, 110.



TABLE 147.—INFLUENCE OF DEGREE OF VULCANIZATION ON SP. GR. (70)

Stock A: rubber, 70; S, 30. Stock B: rubber, 70; S, 30; diphenylguanidine, 1.4. Both vulcanized at 170°

Cure, min	Sp. gr.	
	Stock A	Stock B
15	1.076	1.163
45	1.162	1.174
75	1.167	1.176

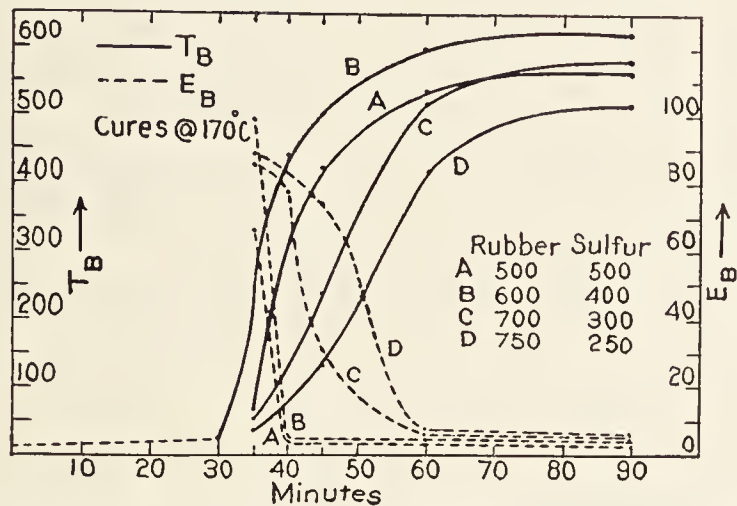


FIG. 116.—Vulcanization of pure gum hard rubber stocks. Influence of the proportions of S on the progressive change in tensile properties (69). Stocks containing rubber and S in the ratios indicated vulcanized at 170°.

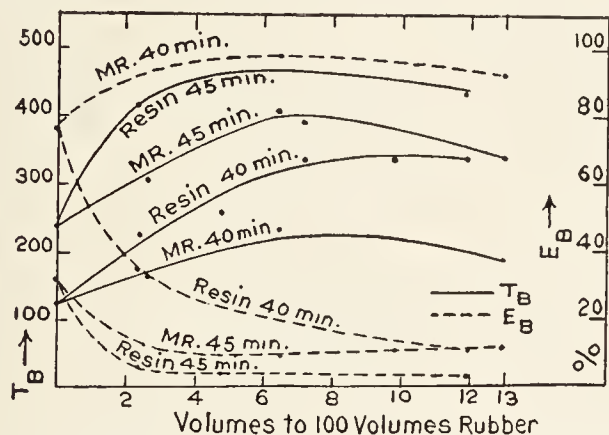


FIG. 118.—Influence of various proportions of MR (mineral rubber) and resin on tensile properties of hard rubber (basal stock: rubber, 70; S, 30 by wt.) vulcanized 40 and 45 min at 170° (straight test pieces) (69).

TABLE 148.—EFFECT OF HEATING ON THE SOFTENING TEMPERATURE, IMPACT STRENGTH AND TRANSVERSE STRENGTH AND THE INFLUENCE OF VULCANIZATION CONDITIONS ON THE IMPACT STRENGTH (46)

Stock A: rubber, 71.43; S, 28.57; vulcanized 12 hr at 149° (3 hr rise). Stock B: rubber, 70.42; S, 28.17; diphenylguanidine, 1.41; vulcanized 12 hr at 149° (3 hr rise). Stock C: rubber, 70.42; S, 28.17; diphenylguanidine, 1.41; vulcanized 2 hr at 149° (1 hr rise). Test bars: 7.5 × 1.25 × (4.75–6.25) cm.

	Stock	Initial	After heating in air							
			At 70°		At 149°					
			7 da	14 da	5 hr	10 hr*	15 hr*	25 hr*	40 hr*	60 hr*
Softening temperature, °C†	A	77.8	91.7	91.1	78.3			82.8		
	B	80	87.8	90	82.8	87.2	82.2	82.2	73.9	67.2
Transverse strength (kg/cm²)§	A	857.8	1040.4	1047.5	984.3			991.2		485.1
	B	822.4	1061.3	1040.3	1019.2	1064.4	998.2	984.1	534.2	400.7
Impact strength (kg cm/cm²)	A	41.1	41.26	25.72	19.13			6.40		2.32
	B	47.70	21.61	30.37	10.90	19.49	13.40	7.14	3.99	2.32
	C	71.64	25.37	25.01	9.47			5.36		1.43

\* Heating intermittent: 5 hr daily on successive days.

† Heating continuously.

‡ Under the load at which excessive flow begins; 5 cm between supports.

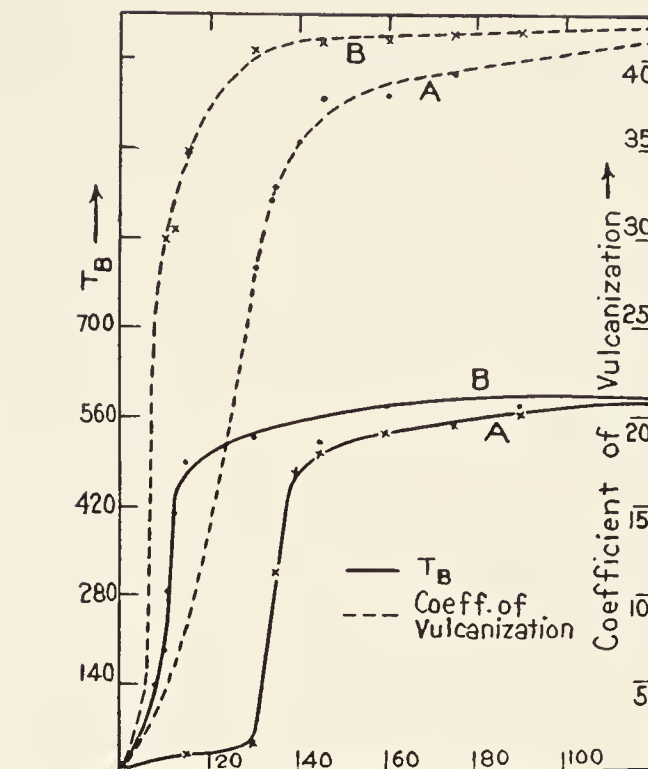


FIG. 117.—Tensile strength and vulcanization coefficients of pure gum hard rubber stocks vulcanized for various periods at 170°. Stock A: rubber, 70; S, 30. Stock B: rubber, 70; S, 30; diphenylguanidine, 1.4 (70). Data are also given in this article for other accelerators.

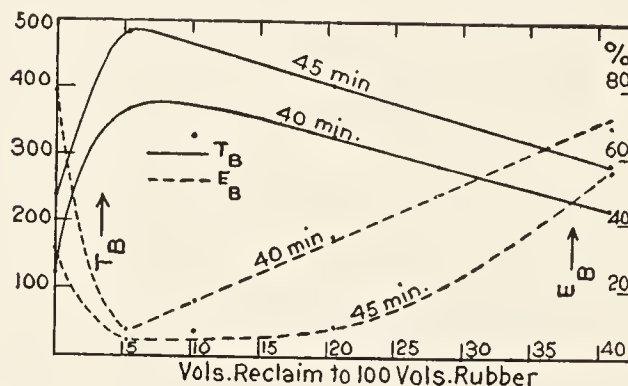


FIG. 119.—Influence of various proportions of tire reclaim on the tensile properties of hard rubber (basal stock: rubber, 70; S, 30) vulcanized 40 and 45 min at 170°.

§ Dead load producing rupture; 5 cm between supports.

|| 6.25 cm between supports.

## GUTTA-PERCHA AND BALATA

TABLE 149.—CHEMICAL COMPOSITION, SOFTENING POINT, TENSILE PROPERTIES AND ELECTRICAL PROPERTIES OF GUTTA-PERCHA (116)

		Number of samples	Chemical composition, %				Softening		Hard- ening time, min	$T_B$	$E_B$	Insula- tion at 24°, megohm	Induc- tive capacity micro- farad
			Gutta	Rcsin	Dirt	Water	Begins at $t$ , °C	Pliable at $t$ , °C*					
Genuine	Pahang.....	40	78.1	19.2	1.5	1.2	47.7	65.5	3.33	322	427	2 408	0.0535
	Banjer red.....	70	67.0	30.2	1.5	1.3	43.8	66.1	6.75	252	384	6 400	0.0559
	Bulongan red.....	22	68.6	29.0	1.4	1.0	45.5	63.3	8	250	419	7 643	0.0552
Soondie	Bagan.....	21	57.5	40.9	1.0	0.6	40.0	61.6	9.5	172	379	5 728	0.0524
	Kotaringin Goolie red....	48	55.2	42.9	1.2	0.7	39.4	60.5	20	148	372	3 739	0.0563
	Serapong.....	31	56.2	42.4	0.9	0.5	40.5	60.5	15.75	167	391	33 590	0.0537
White	Bulongan.....	7	52.2	45.4	1.5	0.9	41.1	67.7	23.5	172	426	44 220	0.0570
	Mixed.....	8	49.8	47.4	1.1	1.7	42.7	76.1	21.5	179	364	67 800	0.0606
	Banjer.....	9	51.8	44.1	1.8	2.3	42.2	73.3	28.5	204	409	50 060	0.0624
Medium quality cleaned.....			54.7	39.4	2.7	3.2	37.7	58.8	17	112	360	34 970	0.0613
Medium quality hardened by ex- tracting resin.....			93.0	2.8	2.5	1.7	57.2	91.1	0.75	399	285	27 410	0.0575

\* Temperature at which a strip 70 mm × 25 mm × 2 mm tears under a load of 14.2 g.

TABLE 150.—CHEMICAL COMPOSITION OF BALATA (87)

		Chemical composition, %			
		Gutta	Resin	Dirt	Water
Commercial	Brazilian block.....	46.7	38.7	3.4	11.2
	Prime Amazonian....	45.9	35.9	2.8	15.4
	Iquitos.....	46.2	46.0	0.4	7.4
	Demerara.....	42.6	48.0	3.7	5.7
Cleaned balata.....		52.6	45.3	0.54	1.57

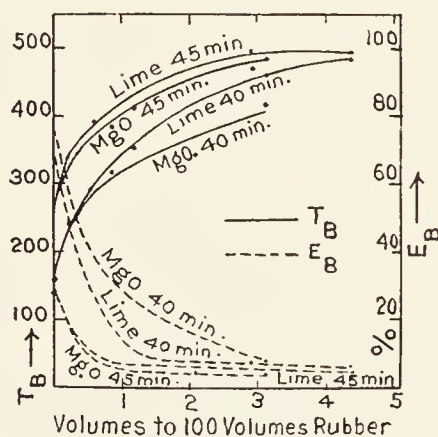


FIG. 120.—Influence of various proportions of lime and magnesia on the tensile properties of hard rubber (basal stock: rubber, 70; S, 30 by wt.) vulcanized 40 and 45 min at 170° (straight test pieces) (69).

TABLE 151.—PROPERTIES OF LEAF GUTTA-PERCHA (171)

	Number of samples	Chemical composition, %				Surface resistivity* at 5 000 — 10 000 volt, ohm	Dielectric strength, kv-em
		Gutta	Resin	Dirt	Water		
Tjipetir....	2	77.2	6.85	11.55	4.3	$0.5 \text{ to } 14 \times 10^{13}$	210 to 310

\* Tests with 6 sheets of different thicknesses.

For further data on electrical properties, *v.* Tables 96–99.

## Chemical Character of the Resin of Gutta-Percha

Saponification No. (4 samples), 79.8 to 77.3; acid No. (4 samples), 5.0 (14). Contains:

Fluavile, amorphous, molten at 100°,  $C_{20}H_{32}O$  (119), or  $C_{40}H_{64}O_3$  (116), soluble in cold alcohol.Albane, M. P. ca. 160°,  $C_{20}H_{32}O_2$  (119), soluble in boiling alcohol, insoluble in cold alcohol.

Nitrogen content of Gutta-Percha, 0.83 % (150).

## Physical Properties of Gutta-Percha and Balata

Refractive index, 1.52 (108).

Specific heat at 4.5°, 0.402 g-cal/g (88).

Linear expansion (2.4 to 5.8°), 0.0001575 cm per °C (88).

Specific gravity (116).

	Gutta-Percha (leaf)	Gutta-Percha	Gutta-Percha	Gutta-Percha	Balata
Number of samples....	1	3	3	3	
Gutta/resin ratio.....	5.19	3.8	1.37	1.37	
Sp. gr., mean.....	0.9625	0.9879	0.9735	1.0063	0.9731

TABLE 152.—SOFTENING POINT AND VISCOSITY OF GUTTA-PERCHA (48)

	% composition		Softening point, °C	Viscosity (2 % soln. in $CCl_4$ )
	Gutta	Resin		
Tjipetir.....	74.98	11.09	60	1.60
White.....	49.10	48.65	50	1.44
Salai prima.....	33.76	48.58	47	1.59
Gulai sekunda.....	29.54	55.39	37	1.33
Akassa.....	12.83	73.19	42	1.41
Siak.....	14.34	69.50	35	1.02
Penang.....	20.41	65.12	40	1.12

TABLE 153.—EFFECT OF COMPOUNDING INGREDIENTS ON THE SOFTENING TEMPERATURE OF GUTTA-PERCHA (49)  
Sample of Gutta-Percha contained 55.39 % resin

Ingredient	None	Kieselguhr	Barytes	MgO	
% ingredient.....	0	100	70	100	140
Softening temperature	38°	55°	44°	65°	84°

## Water Absorption by Gutta-Percha

TABLE 154.—OSMOTIC PRESSURE AND MOLECULAR WEIGHT OF GUTTA-PERCHA (36)

 $C_6H_6$  soln. of washed and de-resinified Gutta-Percha

% concentration	Osmotic pressure, atm.	Molecular weight
6.03	0.0500	29 500
3.04	0.0238	31 100
2.04	0.0146	34 000
1.26	0.0086	35 600

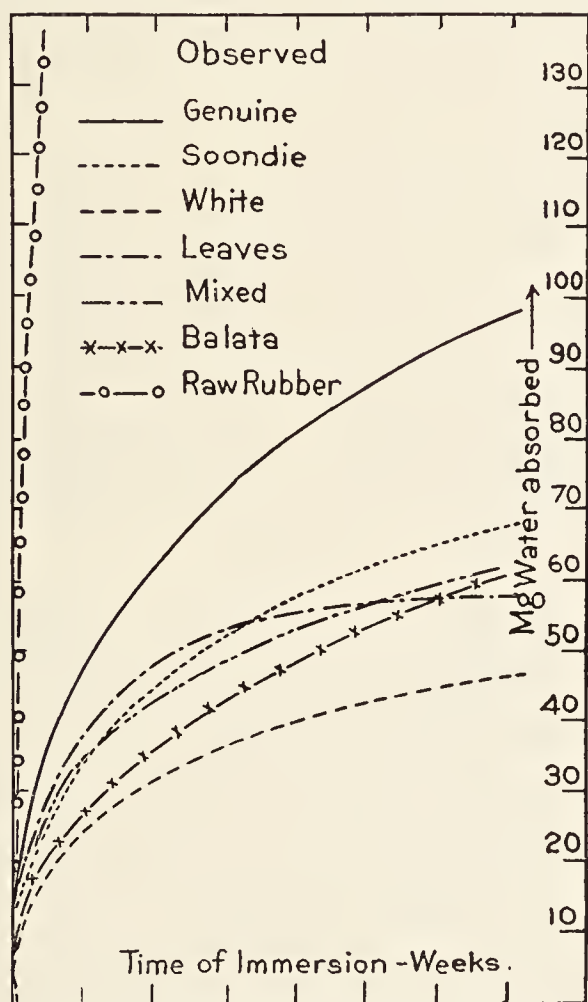


TABLE 155.—RATE OF COMBINATION OF S (153)

Time, hr	Combined S, %	
	Gutta-Percha	Balata
2	3.12	
5		9.43
8	14.12	13.27
15		25.61
25	31.95	31.89
30	31.97	31.85

TABLE 156.—VULCANIZATION OF MIXTURES OF RUBBER AND GUTTA-PERCHA (87)

Composition			Vulcanization at 148°									
Rubber	Gutta-Percha	S	45 min		60 min		75 min		90 min		120 min	
			T <sub>B</sub>	E <sub>50</sub>	T <sub>B</sub>	E <sub>50</sub>	T <sub>B</sub>	E <sub>50</sub>	T <sub>B</sub>	E <sub>50</sub>	T <sub>B</sub>	E <sub>50</sub>
90	0	10	74	885	120	813	143	766	157	715	170	715
88	2	10	49		93	915	111	830	135	788		
86	4	10	72	900	100	865	112	817	170	750		
80	10	10	60	893	133	865	159	810	158	748		

FIG. 121.—Water absorption (in mg) of different classes of Gutta-Percha and of balata. Thickness of sheet 2.2 mm, area 100 cm<sup>2</sup>, wt. 10 g (116).

## LITERATURE

(For a key to the periodicals see end of volume)

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## FACTITIOUS PLASTICS

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### A. NITROCELLULOSE ("PYROXYLIN") PLASTICS<sup>1</sup>

Made by the application of heat and pressure to colloidal mixtures of pyroxylin with relatively non-volatile solvent (camphor or substitute for camphor) and volatile solvent (usually ethyl alcohol), followed by evaporation of the volatile solvent; ordinarily containing sufficient non-volatile solvent to insure "plasticity" at 75–90°C—e.g., celluloid, fiberloid, pyralin, pyradiolin, viscoloid, xylonite.

Except as otherwise noted, the data given are for the freshly manufactured, commercial type of camphor product. Photographic film is not covered.

1. *Composition*.—Varies according to manufacturer. The following are illustrations:

#### PYRALIN (7)

Pyroxylin 11% N	Camphor	Stabilizer	Residual volatile solvent	Additions: dyes, pig- ments, etc.
68–75%	23–27%	0.5–1%	1–5%	0–14%

#### VARIOUS FOREIGN AND DOMESTIC SAMPLES (21)

Nitrocellulose	Camphor + solvent	Ash
58–78%	17–31%	0.7–28%

<sup>1</sup> Acknowledgment is made to Mr. A. F. Randolph, du Pont Viscoloid Company, for a critical examination of this section.

### Mechanical

2. *Density*.—g cm<sup>-3</sup>. 1.35 (transparent) to 1.60 (commercial pigmented material)(7).  $d = 1.37 + 0.0125p$ , where  $p = \% \text{ ZnO}$  between 1 and 15 (14). For influence of stretching  $v$ . (16).

3. *Permeability*.—Transparent material of thickness 0.030 in., exposed on one surface to atmosphere dried by CaCl<sub>2</sub> and on other side to summer atmosphere, transmitted moisture at rate of 0.013 g per in.<sup>2</sup> per week (7).

Pyralin, from saturated air to air dried by CaCl<sub>2</sub>, 0.0046 resp. 0.063 in. thick, transmitted moisture at the rate of 0.029 resp. 0.004 g in.<sup>-2</sup> day<sup>-1</sup> in three days (7).

4. *Modulus of Elasticity* (Def. 10a).—Young's modulus = (2.0 to 3.9) × 10<sup>5</sup> lb. in.<sup>-2</sup> (5, 7, 11, 12, 16, 17). Exhibits hysteresis (13).

5. *Elastic Limit*.—Yield point = (3.9 to 7.4) × 10<sup>3</sup> lb. in.<sup>-2</sup>. Varies with thickness and pigment content (5, 7, 12, 16).

6. *Poisson's Ratio*.—0.36 to 0.43 (5, 11).

7. *Tensile Strength* (Def. 4).—Varies with thickness, nature of nitrocellulose, camphor content, and pigment content. (4.9 to 8.5) × 10<sup>3</sup> lb. in.<sup>-2</sup> (7, 11, 12); 6 kg mm<sup>-2</sup> (5). Variation with temp. °C; 20°, 7.5; 70°, 4.5; 90°, 1.0; × 10<sup>3</sup> lb. in.<sup>-2</sup> (7).

8. *Ultimate Elongation at Failure*.—From 10% for 0.005 in. thick up to 40% for 0.2 in. thick; for 0.015 in. thick, from 20 to 30% for 0 pigment, to 15 to 25% for 16% pigment (7), cf. (4, 5).

9. *Resistance to Bending*.—Schopper's folding endurance tester. Sample 0.5 × 4.0 × 0.015 in., double bends of 100° required to break ( $B_D$ ) = 8 to 22.  $B_D = k \times (\text{thickness})^{-1.35}$  (7).



10. *Hardness*.—Brinell, 10.7 to 11.7 (20).  $H = \text{const.} - (0.05 \times \% \text{ ZnO})$ , approx. between 1 and 15%. Method of penetration by loaded sphere (14).

11. *Coefficient of Friction*.—Static, of polished material on self, glass, paper, or planed wood, 0.25 to 0.35 (7).

12. *Viscosity*.—Solutions in camphor-alcohol (15).

#### Thermal

13. *Thermal Expansion*.— $\frac{1}{l} \frac{dl}{dt}$  (20–50°C) = (12 to 16)  $\times 10^{-5}$  (19, 20).

14. *Heat Capacity (Specific Heat)*.—0.34 to 0.38 cal g<sup>-1</sup> °C<sup>-1</sup> (20).

15. *Thermal Conductivity*.—Cal cm<sup>-2</sup> sec<sup>-1</sup> (°C, cm<sup>-1</sup>)<sup>-1</sup>.  $3.1 \times 10^{-4}$  (20).  $5.14 \times 10^{-4}$  (22, 27).

16. *Working Range for Molding*.—85 to 120°C (7).

17. *Permanent Shrinkage on Heating*.—1.4% after two heatings to 100° in air (18); 0.5–1% (7). Variable, depends on amount of internal strain.

18. *Flash Point*.—141 to 185°C for 0.3 g of powder heated 3° per min (15). 160 to 200°, for material of good quality (7, 9). 550 to 640° for edge contact with hot porcelain rod (21).

19. *Loss in Weight at 110°*.—Very variable (7, 9), cf. (21).

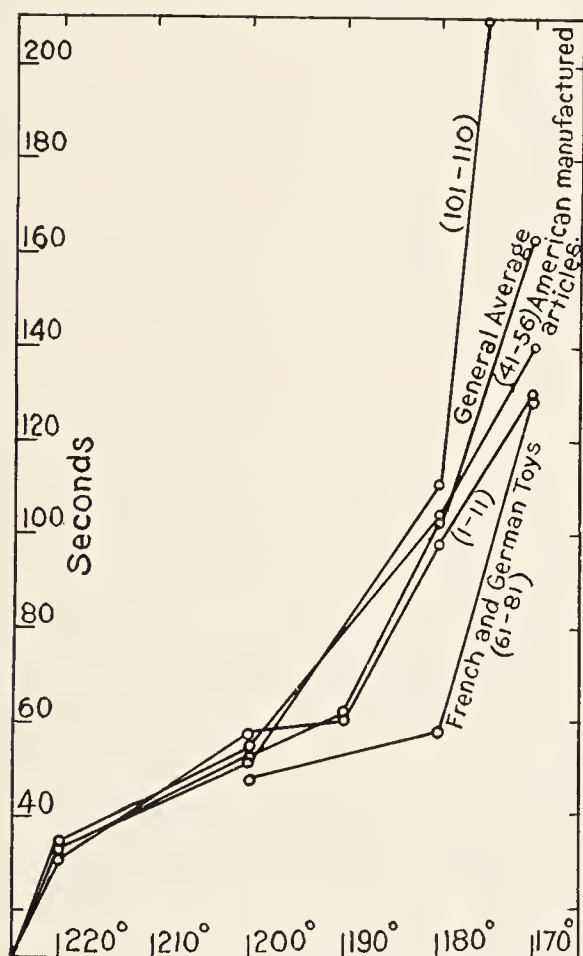


FIG. 1.—Average explosion times.

20. *Explosion Times*.—(21). For improved method of test, v. (24).

Time in seconds	Temperature of metal, °C	Transparent pyralin		Pyradiolin	
		A	B	A	B
(A) to the start, (B) to the finish, of fuming-off or burning of 0.5 × 0.5 × 0.06 in. samples thrown on surface of molten metal	215	63	65	300	330
	225	59	61	58	85
	235	39	42	50	65
	250	22	24	36	47
	275	10	15	12	30
	300	4	13	15	27
	350	3.5	9	8	20

21. *Rate of Combustion*.—For thin strips, 5 to 10 times that of thin paper or wood shavings of same dimensions (21). For composition of gases produced see (21, 25). Pyradiolin, vertically upward about  $\frac{1}{3}$  that of pyralin; horizontally or vertically downward, 0 if flame is removed after ignition (7).

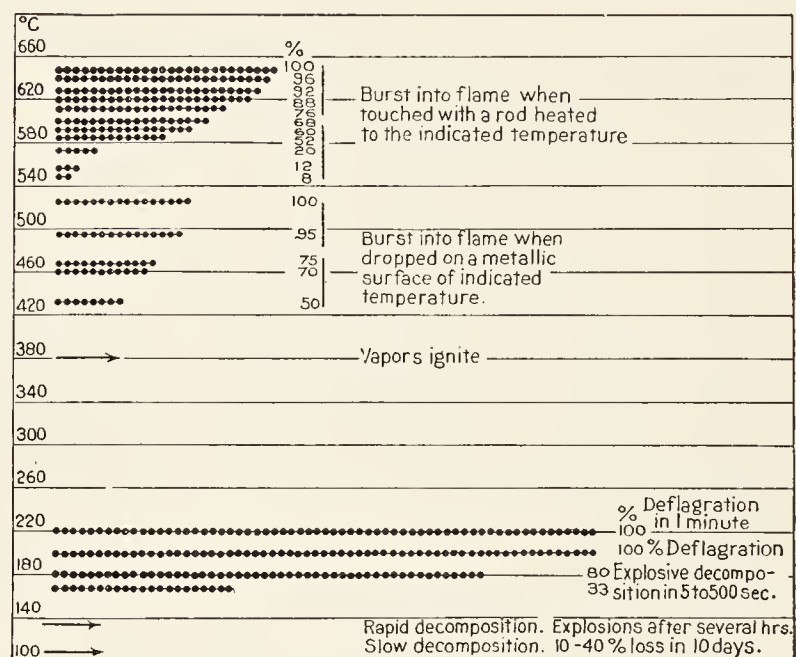


FIG. 2.—Behavior of celluloid at various temperatures.

#### Electrical

22. *Electrical Resistivity*.—Volume resistivity,  $R_v = (2 \text{ to } 30) \times 10^{10}$  ohm-cm. Surface resistivity,  $R_s$ , at 50% humidity, ca.  $3R_v$ ; at 85% humidity, ca.  $0.2R_v$  (3).

(7)	$R_v$ in $10^{10}$ ohm-cm			$R_s$ in $10^{10}$ ohm	
	At 500 v 20°C	50% humidity	Water-soaked	50% humidity	Water-soaked
Transparent pyralin.....	98	7.2	6.6	$>10^4$	36
Pyradiolin.....	2350	2200	840	$>10^4$	600
Source.....	E. T. L.	Croft Lab., Harvard			

23. *Phase Difference (Power Factor)*.—In circular degrees, 3.0 to 4.6° at  $6 \times 10^5$ , 2.5 to 5.3° at  $10^5$  cycles sec<sup>-1</sup> (3).

(7)	P. F.	Phase angle, circular degree							
		1	5	20	100	500	2000	1	
Kilocycles sec <sup>-1</sup> =	(2 kv.) 0.06								
Transparent pyralin.....	2.5%	0.0301	0.026	0.0273	0.0305	0.0350	0.043	0.034*	0.034†
Pyradiolin.....	4.0%	0.0365	0.041	0.0402	0.0340	0.0289	0.025	0.036*	0.038†
Source.....	E. T. L.	Croft Lab., Harvard							

\* = at 50% humidity. † = water-soaked.

24. *Dielectric Constant*.—6.9–8.8 at  $6 \times 10^5$  cycles  $\text{sec}^{-1}$ ; 7.2–9.8 at  $10^5$  cycles  $\text{sec}^{-1}$  (3); 12 at 40 cycles (1).

(7)	(2 kv.)	* = at 50% humidity. † = water-soaked						
Kilocycles- $\text{sec}^{-1}$ =	0.06	1	5	20	100	500	2000	1
Transparent pyralin.....	6.3	7.00	6.78	6.59	6.38	6.19	5.98	7.2* 7.2†
Pyradiolin.....	5.6	5.65	5.42	5.23	4.97	4.79	4.58	5.7* 5.8†
Source.....	E. T. L.	Cruft Lab. Harvard						

25. *Dielectric Strength*.—Averages of 10 determinations using blunt needle-point electrodes under oil. Source: E. T. L. (7).

Material	Thickness, mils	Volts per mil
Pyralin:		
Black.....	60	780
Black.....	215	230
Transparent.....	23.4	900
Transparent.....	63.6	475
Transparent.....	91	270
White.....	211	210
Green transparent.....	200	225
Yellow transparent.....	64	635
Pyradiolin.....	59	780
Pyradiolin.....	60	750

#### Optical

26. *Refractive Index*.— $n_D = 1.46 \pm 0.03$  (7).

27. *Birefringence*.—Celluloid under tension exhibits birefringence. The specific birefringence,  $\frac{N_E - N_O}{\%E}$ , for Na light (where  $E$  is the elongation and  $N_E$ , resp.  $N_O$ , the refractive indices for the extraordinary and ordinary ray resp.), is 0.046 for 0% camphor and decreases to 0.005 for 50% camphor. For constant tension it increases with time. Data *in re* the after effects of tension on birefringence, density, and dispersion are also given in (5, 10, 11, 16).

28. *Coefficient of Absorption*.— $I = I_0 e^{-kt} = 1.81$  and 1.95, two samples (Na light) (11). Cellulose acetate transmits the ultra-violet down to  $230\mu\mu$  (13).

#### Chemical

29. *Chemical and Solvent Action of Various Reagents*.—A, Little or no effect at room temperature. B, Superficial attack, blistering or softening. C, Gelatinization. D, Solution with decomposition. E, Good solvent. F, Not solvent, but becomes good solvent on addition of small amounts of camphor. G, Not solvent, but becomes good solvent on addition of large amounts of camphor. H, Can be used as diluent for E. I, Causes precipitation if used as diluent. Not solvent and does not become solvent on addition of camphor (4, 7, 23, 26).

$\text{H}_2\text{SO}_4$ . <40%, A; 45%, B; 60%, D.

$\text{HNO}_3$ . 14%, A; 25%, B; conc. D.

HCl. 13%, A; 25%, B after several days; 35%, B and D

Acetic acid ( $\text{CH}_3\text{COOH}$ ). Dilute, B; glacial, E.

Alkaline solutions. Weak at room temp., B; with increasing strength or temp., D.

Ketones, diacetone alcohol, wood spirit, methyl, ethyl, propyl, butyl or amyl acetate, nitrobenzene, E.

The lower aliphatic alcohols, C, F.

The ethers and the lower aromatic hydrocarbons, G, H.

$\text{CHCl}_3$ ,  $\text{C}_2\text{H}_2\text{Cl}_4$ ,  $\text{CCl}_4$ , gasoline, turpentine, water, I.

Oils and fats, A, except for castor oil which has slight solvent action.

$\text{SeOCl}_2$ , E.

Pyridine, D.

30. *Absorption of Water*.—(7).

#### TESTS ON STANDARD TRANSPARENT MATERIAL

	Symbol	Thickness 0.015 in.	Thickness 0.860 in.
Net gain in weight of seasoned material, resulting from immersion in water, * %.....	A	1.3 to 2.1	1.6 to 2.3
Hours required to reach approximately maximum wt. and length.....		24	100 to 200
Net increase in length of seasoned material, resulting from immersion in water, * %	M	0.4 to 0.7	0.5 to 0.7
Loss of weight due to extraction of camphor in 2 months, † %.....	B	0.6 to 1.0	0.5 to 2.1
Total water absorbed by seasoned material, † %.....	A+B	2.3 to 2.6	2.8 to 3.2
Loss in weight of seasoned material in atmosphere dried by $\text{CaCl}_2$ , ultimate, %.....	C	1.1 to 1.2	1.4 to 1.6
Hours required to reach approximately minimum wt. and length.....		100 to 200	700 to 1000
Decrease in length over $\text{CaCl}_2$ , %.....	N	0.5	0.5 to 0.7
Maximum capacity for moisture, %.....	A+B+C	3.4 to 3.8	4 to 4.1
Change in length between extremes, %.....	M+N	1 to 1.2	1.2

\* *I.e.*, net effect of absorption of water; extraction of camphor; replacement of alcohol by water (probably negligible).

† Neglecting replacement of alcohol by water.

31. *Molecular Complexity*.—"Films of celluloid have been made on water by evaporation of a dilute solution. The thinnest stable films are  $10 \text{ \AA}$  thick, indicating that the molecular complex of celluloid is not over  $10 \text{ \AA}$  in diameter" (2).

#### LITERATURE

(For a key to the periodicals see end of volume)

- (1) Addenbrooke, 121, 66: 629; 11. (2) Barton and Hunt, 58, 114: 861; 24. (3) U. S. Bureau of Standards, O. (4) Clement and Riviere, *La Cellulose*, Paris, 1920, p. 308–315. (5) Coker and Chakko, 62A, 221: 139; 20. (6) Curtis, 31A, 11: 359; 14. (7) du Pont Viscoloid Co., O. (8) Electrical Testing Laboratories, New York City, O. (9) The Fiberloid Corporation, O. (10) Filon and Jessup, 5, 101: 165; 22. (11) Heymans and Allis, 285, 2: 217; 23. (12) Heymans and Calingaert, 45, 16: 939; 24. (13) Martin, 248, 6: 323; 22. (14) Nishida, 296, 4: 287; 14. (15) Nishida, 45, 8: 1096; 16. (16) Ramspech, 8, 74: 722; 24. (17) Rossi, 71, 16: 206; 10. (18) Souder and Hidnert, 31A, 15: 408; 19. (19) Souder and Hidnert, U. S. Bureau of Standards, O. (20) Stifler, Columbia University, New York City, O. (21) Stokes and Weber, 32, No. 98; 17. (22) Tesche, 97, 5: 233; 24. (23) Ullmann, B61, III: 303; 15. (24) Weber, 31, No. 192; 12. (25) Will, 92, 19: 1382; 06. (26) Worden, *Nitrocellulose Industry*, I, Chap. IV (New York, Van Nostrand, 1911). *Technology of Cellulose Esters*, I, 2655–2759 (New York, Van Nostrand, 1921). (27) Dickinson and Van Dusen, 382, 3: 5; 16.

#### B. PHENOL RESINS AND THEIR PRODUCTS

("Bakelite," "Redmanol," "Condensite," Etc.)

L. V. REDMAN

Commercial Phenol Resins are phenol-formaldehyde condensation products, prepared under conditions that produce a resin capable of becoming hard, strong, insoluble and infusible with application of heat and pressure. Phenol Resin Products include: (1) Pure Resin; (2) Molded Products (employing as fillers wood flour, asbestos or other fibrous materials); and (3) Laminated



Products (prepared from paper or cloth which has been previously impregnated with the uneured resin).

The information given below is based upon data from (1, 2).

#### TYPE OF MATERIAL

Type	Molded, and filled with			Laminated and filled with			Pure resin
	Wood flour	Asbestos	Mica	Paper	Canvas	Cloth	
Symbol	M <sub>w</sub>	M <sub>A</sub>	M <sub>M</sub>	L <sub>P</sub>	L <sub>C</sub>	L <sub>Cl</sub>	P

**Tensile Strength.**—One-half inch figure-8 shaped test pieces for M and P materials (A. S. T. M. [D-48-24]). For L materials, values are parallel to laminations; *v.* (3) for shape of test piece.

Tensile strength =  $A \times 10^3$  lb. in.<sup>-2</sup> =  $A' \times 10^7$  dyne cm.<sup>-2</sup>.

Type	M <sub>M</sub> , M <sub>w</sub> and M <sub>A</sub>	L <sub>P</sub>	L <sub>C</sub>	P
A.....	3.5–6.0	8.7–25	8.5–12	5–11
A'.....	24–40	60–175	62–80	35–75

**Compressive Strength.**—Inch-cube test-piece. (A. S. T. M. [D-48-24].) Compressive strength =  $A \times 10^3$  lb. in.<sup>-2</sup> =  $A' \times 10^7$  dyne cm.<sup>-2</sup>; at 20° unless otherwise noted; parallel or perpendicular to laminations as indicated.

Type	M <sub>w</sub>	M <sub>w</sub> , 100°	M <sub>A</sub>	L <sub>P</sub>	L <sub>C</sub>	L <sub>C</sub> ⊥	P
A...	25–36	12	18–36	20–45	20–25	35–47	26–33
A'..	175–250	80	125–250	140–275	140–175	245–330	180–230

**Modulus of Elasticity in Tension, Young's Modulus.**— $M = 1.5\text{--}2.5 \times 10^6$  lb. in.<sup>-2</sup> =  $1.1\text{--}1.75 \times 10^{11}$  dyne cm.<sup>-2</sup> for the L<sub>P</sub> material parallel to laminations; *v.* (3) for sample used.

**Modulus of Elasticity in Bending.**—Samples 12 in. long by 1 in. wide, with 10 in. span.  $M = \text{load} \times \text{span}^3 \div 4 \times \text{width} \times \text{thickness}^3 \times \text{deflection at center} = 1.1\text{--}2.1 \times 10^6$  lb. in.<sup>-2</sup> =  $75\text{--}175 \times 10^9$  dyne cm.<sup>-2</sup> for the L<sub>P</sub> material ⊥ to laminations.

**Modulus of Rupture.**—Samples 12 in. by 1 in. by 0.25 in.; 10 in. span.  $M = 3 \times \text{load} \times \text{span} \div 2 \times \text{width} \times \text{thickness}^2 =$ , for L<sub>P</sub> material, 15 000–30 000, and for P material, 12 500–20 000 lb. in.<sup>-2</sup> = for L<sub>P</sub>,  $1.05\text{--}2.10 \times 10^9$  and for P,  $0.85\text{--}1.40 \times 10^9$  dyne cm.<sup>-2</sup>.

**Impact Behavior.**—(a) Olsen impact machine. Test piece  $2\frac{1}{2}$  in. × 1 in. ×  $\frac{1}{2}$  in. with edges and corners rounded, 2 in. span. Drop increments of  $\frac{1}{2}$  in. between blows, from zero up to the breaking point. The values given below are the sums of the corresponding mass-height products.

Type		M <sub>W</sub>	M <sub>A</sub>	L <sub>P</sub>	L <sub>C</sub> ⊥	P
Σ mh	lb. in.	500–1200	200–540	400–2000	3500–5300	500–1750
	kg cm	575–1380	230–620	460–2300	4000–6000	575–2000

(b) Pendulum method. Energy of blow to break a  $\frac{1}{2}$  in. square sample. L<sub>P</sub>, || 0.3–1.5 lb. ft.; 0.04–0.20 kg m; L<sub>C</sub>, || 2–3 lb. ft.; 0.25–0.40 kg m.

**Bulk Density and Hardness.**—Brinell test by application of 500 kg wt. for 30 sec. Scleroscope test with hard hammer.

Type	M <sub>w</sub>	M <sub>A</sub>	L <sub>P</sub>	L <sub>C</sub>	P
<i>d</i> , g cm. <sup>-3</sup>	1.33–1.40	1.78–2.00	1.32–1.40	1.36–1.40	1.20–1.29
Brin...	30–38	38–42	35–45	33–38	30–45
Scler...	78–92	75–95	84–94	60–67	75–110

**Water Absorption.**—Per cent gain in weight of sample ( $5 \times 10 \times 1\frac{1}{4}$  cm) after 24 hr immersion in water at 20°.

Type	M <sub>w</sub>	M <sub>A</sub>	L <sub>P</sub>	L <sub>Cl</sub>	P
Per cent gain.....	0.05–0.20	0.05–0.10	0.20–1.0	0.20–2.0	0.05–0.07

**Softening Point Under Load.**—A. S. T. M. method [D-17-T-1919]. M<sub>w</sub>, 125–130; M<sub>A</sub>, 130–150; L<sub>P</sub>, 125–150; P, 75–100; deg. C. Do not flow under pressure of screw heads and similar forces at ordinary temperatures.

**Thermal Expansion and Specific Heat.**—Mean coefficient of linear expansion =  $A \times 10^{-6}$  per °C between 20 and 70°. Specific heat, *e*<sub>1</sub> in joules g.<sup>-1</sup> per °C, *e*<sub>2</sub> in cal g.<sup>-1</sup> per °C or BTU lb.<sup>-1</sup> per °F.

Type	M <sub>w</sub>	M <sub>A</sub>	L <sub>P</sub>	L <sub>C</sub>	P
A.....	25–45	20–45	20–30	20–30	50–110
<i>e</i> <sub>1</sub> , joules....	1.2–1.5	1.5–1.7	1.2–1.7		1.4–1.5
<i>e</i> <sub>2</sub> , cal or BTU....	0.30–0.36	0.35–0.40	0.30–0.40		0.33–0.37

**Electrical Resistivity.**—At 20°C and 50% atmospheric humidity the total resistivity (in ohm) is of the order of  $10^{10}\text{--}10^{11}$  for most types, that for the M<sub>A</sub> material being somewhat lower,  $10^8\text{--}10^9$ , and that for the pure resin sometimes higher,  $10^{10}\text{--}10^{12}$ . The surface resistivity for L<sub>P</sub> (in  $10^9$  ohm) is 10–90 000 for 24%, 0.9–660 for 50% and 0.1–15 for 84% relative humidity. Exposure to light, especially ultra-violet, decreases surface resistivity.

**Dielectric Constant (ε) and Power Factor.**—At radio frequencies. Phase difference = power factor (P. F.) × 0.57.

Type	M <sub>w</sub>	M <sub>M</sub>	L <sub>P</sub>	L <sub>Cl</sub>	P
ε.....	4.5–7.5	4–5	4.5–6.0	4.5–6.0	4.5–7.0
P. F., %..	1.5–7	0.5–1.5	1.5–5	2–7	0.2–3

**Dielectric Strength.**—A. S. T. M. low frequency test. L and P materials in  $\frac{1}{32}$  in. sheets.

Type	M <sub>w</sub>	M <sub>A</sub>	L <sub>P</sub>	L <sub>C</sub>	P
Volts mil. <sup>-1</sup> .....	250–700	150–500	750–1300	250–500	250–700
Kilovolts cm. <sup>-1</sup> .....	100–280	60–200	300–500	100–200	100–280

**Flash-over Voltage.**—Between two 2 cm skirted brass studs 2 cm apart. Radio frequencies, L<sub>P</sub>, 18–28; L<sub>C</sub>, 18–25 kilovolts.

**Optical Properties.**—For the pure resins,  $n_D^{20} = 1.62\text{--}1.70$ . Quite transparent in the infra-red. Darkening occurs on long exposure to sunlight.

**Miscellaneous Effects.**—Exposure to (1) steam, does not affect mechanical properties but increases water absorption; (2) weak acids, no effect; (3) strong acids, charring of the organic fillers; (4) strong oxidizing acids, disintegration of the resin; (5) mild alkalis, softening; (6) strong alkalis, disintegration; (7) organic solvents, no effect; (8) aging, no effect.

#### LITERATURE

(For a key to the periodicals see end of volume)

- (1) Bakelite Corporation, Research Lab., *O.* (2) Dellinger and Preston, *31*, No. 216; 22. (3) Dellinger and Preston, *32*, No. 471; 23. (4) A. S. T. M., American Society for Testing Materials.

#### C. COMPARISON OF PROPERTIES OF HARD RUBBER, VULCANIZED FIBER, LAMINATED AND MOLDED PHENOLIC INSULATING MATERIALS<sup>1</sup>

Hard rubber is composed of crude rubber, sulfur, and usually some mineral filling compound. The relatively high cost of crude rubber had induced some makers of hard rubber to use reclaimed rubber or else load the new rubber with a high percentage of mineral filler. The lack of a proper understanding of this fact between the maker and the user has often resulted in unjust censure of hard rubber as an insulator. The better grades of hard rubber are made of new rubber containing no mineral filler

<sup>1</sup> Dellinger and Preston, *32*, 216: 619; 22.

and are free from excess sulfur. With these points in mind it is evident that the values assigned to a particular property or the effect of a certain test must necessarily be broad. Neither the best nor the poorest grade of hard rubber is considered in the data and opinions given in the following table.

*Vulcanized fiber* is made of parchmented paper. For the better grades of fiber, rag base paper is used. The paper is run slowly through a warm concentrated solution of sulfuric acid or zinc chloride, the one solution being used in making fiber sheets one-eighth inch thick or less, the other solution being used for thicknesses greater than one-eighth inch. The purpose of the acid or zinc chloride is to soften the walls of the cellulose (cotton) fibers, so that when several sheets of treated paper are pressed together the fibers tend to mat and cohere. The treated paper is wound on a drum until the cylindrical tube of the desired thickness is obtained, the cylindrical tube being then cut so as to form a sheet whose width is equal to the width of the paper and whose length is equal to the circumference of the drum. The composite sheet of treated paper is then soaked in water to remove the acid or zinc chloride, dried, and pressed. The term "vulcanized" is somewhat misleading. Fiber does not depend upon heat and pressure to cure it as does hard rubber.

Vulcanized fiber varies much in both mechanical and electrical properties. The properties depend somewhat on the quality of rags used, the amount of residual sulfuric acid or zinc chloride, and upon the density of the finished product. Since the various processes of fiber making are difficult to control, the following statements relative to fiber must be taken as general and the recorded numerical data as average data.

The several makes and many grades of *laminated phenolic insulating material* are discussed quite fully in the paper. Any numerical value or statement given in the following summary table is an approximation.

The *molded phenolic insulating materials* are subject to as many variations as hard rubber. There is probably not as much variation in the phenolic resin binder in the molded phenolic materials as there is in the crude or reclaimed rubber binder of hard rubber. There are many other chances for variation in the press pressure and temperature, length of curing in the presses, and kind and quality of filler. Some of the fillers used are wood flour, pulverized mica, and asbestos. The kind and amount of filler will affect both the mechanical and electrical properties. All these possible variations make the data only approximate and require rather general statements in the summary table.

Most of the numerical data given in the table below are from tests made at the Bureau of Standards. The statements concerning the effects of various things on the different insulating materials are based on the experience of various members of the Bureau of Standards staff and upon the experience of the manufacturers of these materials. The manufacturers' experience on hard rubber and vulcanized fiber extends over many years, while the experience on the phenolic insulating materials is much more limited.

While it is possible to make up insulating materials which would give results different from those recorded for any particular property, yet it is believed that this table gives information in a condensed form which will serve to show some of the limitations as well as some of the possibilities of these various materials as now obtainable commercially.

COMPARISON OF PROPERTIES OF HARD RUBBER, VULCANIZED FIBER, LAMINATED AND MOLDED PHENOLIC INSULATING MATERIALS

Properties	Hard rubber	Vulcanized fiber	Phenolic insulating materials	
			Laminated	Molded
Surface resistivity at 50 % relative humidity, ohm .....	$10^{12}$ to $>10^{15}$		$10^{11}$	$10^{11}$
Phase differences ( $\psi$ ) at radio frequencies, deg .....	0.5*	3.0†	1.5 to 4.0	1.5 to 4.0
Dielectric constant ( $\epsilon$ ) at radio frequencies.....	3.0*	5.0†	4.5 to 6.0	5.0 to 7.5
Dielectric strength, volt/mm...	10 000 to 38 000‡§	9 000 to 16 000‡§	27 000 to 45 000‡§	9 000 to 40 000‡§
Tensile strength, lb./in. <sup>2</sup> .....	3 500 to 6 500	9 000 to 20 000	10 000 to 25 000	3 500 to 7 000
Water absorbed in 24 hr, percentage by weight.....	0.02	26 to 45	0.2 to 1.0¶	0.05 to 0.2**
Density, g/cm <sup>3</sup> .....	1.12 to 1.40††	1.3 to 1.5	1.3 to 1.4	1.3 to 1.4
Thermal expansivity (at 20 to 60°C).....	60 to $80 \times 10^{-6}$	$27 \times 10^{-6}$	20 to $30 \times 10^{-6}$	25 to $45 \times 10^{-6}$

## Effects of various agents

Age .....	Deteriorates slowly, but if properly vulcanized and protected from the light it is not affected	Improves in quality by seasoning‡‡	Improves§§	No depreciation in physical or chemical properties; slight increase in hardness§§
Heat.....	At 65.5°C (150°F) pure hard rubber softens perceptibly; at 100°C (212°F) it is so soft it may be bent easily; at 115.5°C (240°F) it becomes leathery and may readily be cut with a knife; melts at 200°C (392°F)‡	Will not melt under any circumstances; not readily inflammable; at very high temperature chars and becomes brittle; active combustion begins at about 343°C (650°F)	Not readily inflammable; will withstand continuously a temperature of 149°C (300°F); heat tends to complete the reaction and volatile substances are driven off. Hence, when cooled it shrinks considerably and may split; shrinks and loses in weight above 60°C	See statement for laminated materials for cellulose-filled molded materials. Asbestos-filled and mica-filled materials are much more resistant to heat¶¶



COMPARISON OF PROPERTIES OF HARD RUBBER, VULCANIZED FIBER, LAMINATED AND MOLDED PHENOLIC INSULATING MATERIALS.—(Continued)

	Hard rubber	Vulcanized fiber	Phenolic insulating materials	
			Laminated	Molded
Sunlight.....	Discolors and disintegrates after a few months; the sulfur of the hard rubber is oxidized, forming the equivalent of sulfuric acid; this may take up ammonia from the air or may attack the filling materials and form various sulfates upon the surface; the surface resistivity is greatly reduced***	No effect‡	No visible effect‡‡‡	After two and one-half years some materials show a slight change, such as discoloration or very fine cracks; other materials show no such change‡‡‡‡
Ultra-violet light for 20 hr . . . .	Discolors and disintegrates; the action is as pronounced for a few hours' exposure to ultra-violet light as for many months' exposure to sunlight; the surface resistivity is greatly reduced***	No data	Appreciable lowering of surface resistivity	Appreciable lowering of surface resistivity***
Moist air.....	Hard-rubber compounds excepting those containing organic substances other than rubber are practically moisture proof	Absorbs water freely, but without permanent injury; while saturated it becomes soft and flexible and swells; warps and twists upon drying	Absorbs slight amount of water, reducing dielectric properties‡‡‡	Absorbs slight amount of water, reducing dielectric properties
Steam.....	The only effect is that due to the high temperature	Same as above, except absorption is more rapid	Best grades not affected beyond slight absorption of moisture; after a few days in steam the cheaper grades will swell appreciably and split; superheated steam tends to warp and blister all grades of the material	Absorbs a slight amount of moisture; if steam is superheated, the high temperature will cause decomposition of cellulose-filled materials. The mineral-filled materials are much more resistant to heat
Solvents:				
Acetone.....	Attacks, dissolving oils and free sulfur‡	No permanent effect‡	No effect‡§§§§	No effect‡§§§§
Alcohol.....	Attacks to a slight degree‡	No permanent effect‡	No effect‡§§§§	No effect‡§§§§
Ammonia.....	No effect‡	No permanent effect‡	Strong solutions may cause material to swell‡	No effect other than slight absorption of moisture‡
Aniline .....	Softens at ordinary temperature‡	Not known	Probably no effect‡	Probably no effect‡
Benzene .....	Softens at ordinary temperature‡	No permanent effect‡	Probably no effect‡§§§§	Probably no effect‡§§§§
Carbon bisulfide.....	Dissolves small amount of hard rubber and any free sulfur‡	No permanent effect‡	Probably no effect‡§§§§	Probably no effect‡§§§§
Ether.....	Dissolves small amount of hard rubber and any free sulfur‡	No permanent effect‡	No effect‡	Probably no effect‡§§§§
Naphtha.....	Softens and swells to slight extent‡	No permanent effect‡	Probably no effect‡	Probably no effect‡§§§§
Oil of turpentine.....	Dissolves in boiling oil‡	No permanent effect‡	Probably no effect‡	Probably no effect‡§§§§

COMPARISON OF PROPERTIES OF HARD RUBBER, VULCANIZED FIBER, LAMINATED AND MOLDED PHENOLIC INSULATING MATERIALS.—(Continued)

	Hard rubber	Vulcanized fiber	Phenolic insulating materials	
			Laminated	Molded
Oil:				
Mineral.....	Slight softening†	Slight absorption†	Practically impervious†	Practically impervious†
Organic.....	Unaffected†	Slight absorption†	Practically impervious†	Practically impervious†
Weak acids.....	Unaffected†	Swells due to absorbed water; may be attacked after some time†	Practically unaffected except for absorption of water	Practically unaffected†††
Weak caustic alkalis.....	Unaffected†	Swells due to absorbed water; may be attacked after some time†	Does not successfully resist the action of alkali unless very dilute	Does not successfully resist the action of alkali unless very dilute
Stronger acids (HNO <sub>3</sub> , HCl, H <sub>2</sub> SO <sub>4</sub> ).....	Not attacked by concentrated hydrochloric, hydrofluoric, acetic acids; not attacked by sulfuric acid of less than 1.50 specific gravity or nitric acid of less than 1.12 specific gravity†	Cellulose fiber attacked; soon decomposes	Decomposes; rapidity depends on specific gravity and temperature of acid	Cellulose-filled materials decompose; rapidity depends on specific gravity and temperature of acid. Molding materials made with acid-resistant fillers, such as mica, offer much greater resistance****
Stronger caustic alkalis.....	No effect	Cellulose fiber attacked; soon decomposes	Binder and filler decompose†††	Completely destroyed; speed of the reaction depends on the strength of the solution
Ozone.....	Oxidizes and soon ruins for electrical purposes	No effect†	Not known	Not known
Metallic inserts.....	Rapidly deteriorated by contact with iron or copper, the metals themselves being corroded; the inserts should be coated with tin, paper, unvulcanized rubber, or other mutually protecting medium	No effect†	No effect	No effect
Miscellaneous				
Machining qualities.....	Admits of a high polish; machines less accurately than would be supposed, due to great resiliency; the better the grade the more readily it is machined; quality may be judged roughly by color and texture, toughness, color, and grain of a shaving; has tendency to warp; can be molded but not accurately to size	Admits of a fine finish; may be sawed, punched, drilled, stamped, embossed, turned, planed, bent, tapped; tough, resists shock; can not be molded††††	Admits of a good polish; can be sawed, punched, drilled, stamped, turned, planed, knurled, embossed, milled, tapped either with or against the grain, though not as easily as hard rubber and vulcanized fiber; tough, resists shock; cannot be molded††††	Admits of a fine lasting polish; can be machined, cut, filed, sawed with difficulty; can be molded accurately to size; quite brittle
Cost (1922).....	About \$2 per pound in sheet form	50-80 cents per pound up to 1 inch in thickness; about \$5 per pound for 2 inches in thickness	About \$1 per pound	Cost varies with complexity of steel molds

\* These values were obtained at frequencies between 750 000 and 75 000 cycles per second (400 to 4000 meters wave length), there being very little change throughout this range. The grade of the sample tested is unknown, so values differing somewhat from these might be expected on other samples using different quantities and kinds of filler.

† Values of  $\psi$  and  $K$  may be somewhat lower or much higher, depending on amount of moisture present in the fiber.



‡ Information obtained from sources other than the Bureau of Standards.

§ Values vary with the thickness of sample, kind of filler, shape of electrodes used, rate of increase of voltage, as well as atmospheric conditions under which tests are made.

|| The Railway Signal Association specifications require an absorption when immersed in water at 70°F for 24 hours, not to exceed 45% by weight for one-eighth inch fiber, 30% for three-sixteenth inch fiber, and 26% for one-fourth inch fiber.

¶ Dependent upon nature of surface, surface area, and kind and amount of filler.

\*\* Varies with polish of mold, press pressure, and temperature, length of curing, ratio of resin to filler, kind of filler, and size of sample.

†† The density depends on the amount of sulfur present and increases with the increase in amount of filler. Pure hard rubber ranges from 1.12 to 1.25. A fair commercial quality ranges from 1.25 to 1.40.

‡‡ This means seasoning or aging in a protected place, such as a storage house.

§§ These materials are of comparatively recent development, and hence no information has been gained covering very long periods. Theoretically, under certain conditions the chemical reactions would tend to continue, which would age and improve the material. One manufacturer claims a slight improvement in dielectric properties and a marked improvement in machining qualities when the aging takes place under ordinary atmospheric and temperature conditions. If the aging takes place in a moist atmosphere, the dielectric properties are subject to deterioration.

||| See pages 580 to 583 of Technologic Paper, U. S. Bureau of Standards, No. 216.

¶¶ When subjected to temperatures above 60°C (140°F) some of the volatile matter is driven off, resulting in the shrinking and loss in weight of the material. This can be carried out many times with the same result, the material becoming more brittle. Tests made on these materials show that they are very erratic in behavior and do not expand or contract in a uniform way. It seems altogether probable that a point would be reached after all volatile matters had been driven off, when further subjection to a moderate temperature and subsequent cooling would not result in further shrinkage. This has not been proved experimentally. High temperature will produce decomposition. Further information regarding these tests will be found in Scientific Paper of the Bureau of Standards No. 352. (See also pages 580 to 583 of Technologic Paper, U. S. Bureau of Standards, No. 216.)

\*\*\* A further discussion of the tests at the Bureau of Standards may be found in Scientific Paper of the Bureau of Standards, No. 234.

††† See effect of ultra-violet light.

‡‡‡ See discussion on pages 599 and 600 of Technologic Paper, U. S. Bureau of Standards, No. 216.

§§§ Strong solvents affect the phenolic binder of the material to a limited extent unless the chemical reaction has been carried to the point where it is in the insoluble state. This condition would render the sheet material too brittle for general use. When water is present, the material will absorb it in various amounts.

|||| The effects vary with the materials, different molding mixtures, and acids. Nitric acid is harmful. In general weak acids will mar the surface and attack the edge of a sample soon after they come in contact with the sample, but there is little or no further change.

¶¶¶ See page 608 of Technologic Paper No. 216.

\*\*\*\* The action differs for various materials and grades. Some materials resist the action of a 30% solution of H<sub>2</sub>SO<sub>4</sub> for several months and will withstand hydrochloric acid without any visible sign of attack. On other materials of this class sulfuric and nitric acids attack the surface of the sample and form a protective coating. This ruins the sample as far as further electrical use is concerned, but on removing the sample from the acid and cutting it open it is found that the acid has not penetrated more than one-sixteenth inch after several months' exposure to the acid.

†††† Thin sheets can be pressed to simple shapes when warm.

## COMMERCIAL CARBONS FOR ELECTRICAL USES

N. K. CHANEY

Manufactured carbon articles in the form of rods, plates, blocks, tubes, etc. in a wide variety of shapes are made by molding or extruding specially prepared mixtures of pulverized carbon "flours" with binding materials of tar or pitch, and subsequently carbonizing the binder at high temperatures. The resulting products always consist of a porous mass of carbon particles knit together by the residual carbon resulting from the decomposition of the binding materials. Because of the variations inherent in all manufacturing processes the physical properties of commercial carbons are subject to characteristic variations, the allowable range of which is determined by the service and cost requirements of the consumer. A high degree of precision in the individual determinations is therefore valueless, the typical range of variation being alone significant. Individual values where given must be regarded merely as representative.

CHARACTERISTIC RANGE IN PHYSICAL PROPERTIES OF TYPICAL GRADES OF COMMERCIAL CARBONS (5)

	Resistance milliohm- cm	Density, g/cm <sup>3</sup>		Sclero- scope hardness
		True*	Bulk	
Coke electrodes.....	3.5 -5.0	2.00-2.10	1.53-1.64	
Coal electrodes.....	3.3 -6.3	1.95-2.10	1.50-1.67	
Brushes:				
Electrographitic A..	4.0 -5.0	2.03-2.07	1.50-1.60	49-61
Electrographitic B..	0.8 -1.8	2.16-2.19	1.41-1.61	20-36
Artificial graphite...	2.3 -3.8	2.08-2.10	1.45-1.60	30-45
Natural graphite....	0.25-0.50	2.23-2.27	1.85-2.00	10-20
Are light carbons...	7.0 -8.0	1.85-1.90	1.30-1.40	70-80

\* By immersion in kerosene.

TEMPERATURE COEFFICIENT OF RESISTANCE (3)

t°C	% resistance		t°C	% resistance	
	Carbon	Graphite		Carbon	Graphite
25	100	100	2000	77.6	68.0
400		94	2200		69.0
800		81.5	2400	65.9	
1200	91.6	66.0	2800	50.9	
1600	87.0	65.0	3500	22.4	

THERMAL EXPANSION

	Δt°C	$\frac{10^6 \Delta l}{l \Delta t}$	Lit.
Electrodes:			
Coal.....	220-1820	11.0	(5)
Coke.....	180-1920	7.2	(5)
Graphite.....	440-1720	10	(5)
Graphite.....		0.55 + 0.0032t	(2)
Arc carbon:			
Lampblack.....	25-1000	6.0	(5)
Coke.....		0.32	(4)
Coke.....		1.5	(4)
Coke.....		2.05	(4)
Coke.....		3.0	(4)

MEAN SPECIFIC HEAT, g-cal/g per °C (1)

Δt °C	Carbon	Graphite	Δt °C	Carbon	Graphite
26- 76	0.168	0.165	36- 902		0.324
26-282	.200	.195	47-1193		.350
26-538	.199	.234	48-1180	0.351	
30-752		.290	56-1450	.387	.390
40-892	.314				

## THERMAL CONDUCTIVITY

$$K = \text{g-cal cm}^{-2} \text{ sec}^{-1} (^\circ\text{C, cm}^{-1})^{-1}$$

$10^2 K$	Range, $^\circ\text{C}$	$10^2 K$	Range, $^\circ\text{C}$
Electrographitic brush A <sup>(5)</sup>		39	180–220
2.9	20–43	35	260–340
Natural graphite brush A <sup>(5)</sup>		31	350–450
3.9	20–43	29	440–560
Graphite electrode <sup>(3, 5)</sup>		27	500–700
5.7	20–43	0.019	2800–3200
50	90–110		

## THERMAL CONDUCTIVITY.—(Continued)

$10^2 K$	Range, $^\circ\text{C}$	$10^2 K$	Range, $^\circ\text{C}$
Coke electrode <sup>(3, 5)</sup>		1.7	200–340
0.79	20–40	1.2	240–523
1.6	37–163	1.2	263–543
1.7	105–225	1.2	283–597
1.1	160–325	0.019	3000
1.6	170–330		

## LITERATURE

(For a key to the periodicals see end of volume)

<sup>(1)</sup> Acheson Graphite Co., O. <sup>(2)</sup> Day and Sosman, 45, 4: 490; 12. <sup>(3)</sup> Hansen, 78, 16: 329; 09. <sup>(4)</sup> Muraoka, 8, 13: 307; 81. <sup>(5)</sup> National Carbon Company, O.

## INDUSTRIAL ELECTRICAL INSULATORS

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## Abbreviations

B. D.	Complete breakdown
B. T.	Burning temperature
D	Diameter
d	Specific gravity, room temperature, water = 1
E.	Engler viscometer; data given in Engler degrees
F. T.	Flash point
G	Spark gap = minimum distance between surfaces of electrodes
Max.	Maximum
P. D.	Potential difference between electrodes
P. F.	Power factor
P. Sp.	Preliminary sparking
S. T.	Solidifying temperature
S. U.	Saybolt Universal viscometer; data given are times of efflux, seconds
V	Viscometer value. For interconversion of E. and S. U. data, and for conversion of either to kinematic viscosity, see Vol. I, p. 33
% Δ	Per cent deviation from mean
ε	Dielectric constant
ρ	Volume resistivity

## Abréviations

B. D.	Rupture diélectrique complète
B. T.	Température de combustion
D	Diamètre
d	Poids spécifique, à la température de la chambre, eau = 1
E.	Viscosimètre d'Engler; données en degrés Engler
F. T.	Point d'inflammabilité
G	Distance explosive = distance minimum entre les surfaces des électrodes
Max.	Maximum
P. D.	Différence de potentiel entre électrodes
P. F.	Facteur de puissance
P. Sp.	Lueur préliminaire
S. T.	Température de solidification
S. U.	Viscosimètre universel de Saybolt; les valeurs données sont les durées de l'écoulement en secondes
V	Constante du viscosimètre. Pour l'interconversion des valeurs de E. et S. U., et pour la conversion de ces deux valeurs en viscosité cinématique, voir Vol. I, p. 33
% Δ	Pourcentage d'écart de la moyenne
ε	Constante diélectrique
ρ	Résistivité



## Abkürzungen

B. D.	Dielektrische Festigkeit
B. T.	Brenntemperatur
<i>D</i>	Durchmesser
<i>d</i>	Spezifisches Gewicht, Zimmertemperatur, Wasser = 1
E.	Engler Viskosimeter, Werte in Englergraden
F. T.	Entflammungspunkt
<i>G</i>	Funkenstrecke = minimal Entfernung der Oberflächen der Elektroden
Max.	Maximum
P. D.	Potentialdifferenz zwischen den Elektroden
<i>P. F.</i>	Kraftfaktor
P. Sp.	Glimmentladung
S. T.	Erstarrungstemperatur
S. U.	Saybolt Universalviskosimeter, die angegebenen Daten sind Ausflusszeiten in Sekunden
<i>V</i>	Viskosimeterwert. Für die gegenseitige Abmessung von <i>E</i> und <i>S. U.</i> Werte, für die Umrechnung auf die kinematische Viskosität siehe Vol. I, p. 33
% $\Delta$	Prozentuelle Abweichung vom Mittel
$\epsilon$	Dielektrizitätskonstante
$\rho$	Widerstand im Inneren

## Abbreviazioni

B. D.	Interruzione continua
B. T.	Temperatura di combustione
<i>D</i>	Diametro
<i>d</i>	Peso specifico, temperatura ordinaria, acqua = 1
E.	Viscosimetro di Engler, valori in gradi Engler
F. T.	Punto di infiammabilità
<i>G</i>	Lunghezza di scintilla = distanza minima tra le superficie degli elettrodi
Max.	Massimo
P. D.	Differenza di potenziale tra gli elettrodi
<i>P. F.</i>	Fattore di potenza
P. Sp.	Preliminare scintillamento
S. T.	Temperatura di solidificazione
S. U.	Viscosimetro universale Saybolt; i valori riportati rappresentano tempi di efflusso in secondi
<i>V</i>	Valore viscosimetrico. Per la conversione dei valori <i>E.</i> in <i>S. U.</i> e viceversa, e per la conversione degli uni e degli altri in viscosità cinematica, vedi Vol. I, p. 33
% $\Delta$	Deviazione percentuale della media
$\epsilon$	Costante dielettrica
$\rho$	Resistività di volume

## INSULATING OILS

J. B. WHITEHEAD AND J. H. LAMPE

Only oils commonly used in industrial electrical apparatus are considered in this section. For data on other oils which might possibly meet industrial requirements, reference must be made to other sections of this volume. Among the following data are some for 7 distinct samples of domestic (U. S. A.) oil; these oils are here designated by the letters A to F, inclusive.

On n'utilise dans les appareils électriques que les huiles minérales de paraffine; on n'a considéré que de telles huiles dans cette section. Pour les données relatives à d'autres huiles qui peuvent présenter, éventuellement, une utilisation industrielle, il faut s'adresser à d'autres sections de ce volume. Parmi les données suivantes, il s'en trouve pour 7 échantillons distincts d'huiles indigènes (U. S. A.); ces huiles sont désignées par les lettres A à F, inclusivement.

Es werden nur Mineralöle paraffinischen Ursprunges in den elektrischen Apparaten benutzt, nur solche sind deshalb Gegenstand des Abschnittes. Für Zahlenwerte weiterer Öle, welche vielleicht industrielle Beachtung verdienen, muss an anderer Stelle dieses Bandes nachgesehen werden. Unter den folgenden Werten sind 7 von heimischen (U. S. A.) Ölproben vorhanden. Diese Öle sind hier vom Buchstaben A bis einschliesslich F angeführt.

Solo gli olii minerali di paraffina sono adoperati negli apparecchi elettrici, e solo essi perciò sono qui presi in considerazione. Per le caratteristiche di altri olii che potrebbero eventualmente soddisfare alle richieste vedi altri capitoli di questo stesso volume.

Tra i valori che seguono sono riportati quelli di 7 campioni di olii degli S. U. A. Questi olii sono indicati con le lettere da A a F inclusa.

TABLE 1.—GENERAL PROPERTIES OF VARIOUS INSULATING OILS

For dielectric strength, see Table 2. Bracketed numbers indicate the range of variation; e.g., first entry indicates that *d* varies from 0.846 to 0.915.

Unit of  $\rho$  =  $10^{12}$  ohm-cm; of  $\epsilon$  = 1 egse; of *P. F.* = 1%; of temperature = 1°C.

Prop.	Oil	U. S. A.			Germany*		France	Japan
		W. E. & M. (20)	G. E. (10)	Tobey (23)	Schen- dell (18)	Stern (22)	Crus- sard (4)	Hirobe (8)
<i>d</i>		{ 0.846 0.915	{ 0.83 0.93	{ 0.845 0.870	{ 0.85 0.92	{ 0.85 0.95	{ 0.85 0.92	{ 0.827 0.861
<i>V</i>		{ 50 100 S. U. 40°	{ 40 120 S. U. 40°	{ 40 110 S. U. 40°	{ 8° 10° E. 20°	{ 8° 8° E. 20°	{ 8° 8° E. 20°	{ 1.43° 2.96° E. 30°
$\rho$		13.2	{ 20 150					
$\epsilon$		2.5	2.15					
S. T.		{ -2 -34	{ 0 -40	{ -10 -15		-5	-1	
F. T.		{ 140 170	{ 130 190	{ 130 190 140 215	{ 160 170 180 190	160	160	{ 125 152
B. T.							180	
<i>P. F.</i>		0.44	{ 0.03 0.06					

\* Heat conductivity of a German oil is given as 0.00031 cal/(cm deg sec) (24).

TABLE 2.—DIELECTRIC STRENGTH OF VARIOUS TRANSFORMER OILS

Average effective breakdown voltage

Unit of voltage = 1000 effective (r. m. s.) volt; of *D* and *G* = 1 in. = 2.54 cm.

Diameter ( <i>D</i> ) Gap ( <i>G</i> )	Sphere 0.5 0.15	Disk 0.5 0.15	Needle points 0.15	Disk point 0.15	Disk 1 0.1	Lit.
Tobey.....			18.0	16.5		(23)
Digby & Mills.....	11.5		17.5	11.0		(3)
N. E. L. A.....	40.0	29.0				(12)
Peek.....	64.0	31.0	22.0			(13, 14)
Hirobe.....	92.0	62.0		15.0		(8)
Schroter.....	92.0					(19)
Everest.....	20.0	20.0	22.0	18.5		(5)
W. E. & M.....	61.5	48.0			36.2	(1)
Vac. Oil Co.....	51.7	37.1			24.0	(1)
B. S.....	61.3	49.9			28.2	(1)

TABLE 3.—DIELECTRIC STRENGTH OF INSULATING OIL E (5, 25)

Breakdown voltage: Effective (r.m.s.) kilovolt  
Units of  $D = 1$  in.; of  $G = 0.001$  in.; 1 in. = 2.54 cm.

$G$	Sphere, $D = 0.5$				Disk, $D = 0.5$				Needle points				Point, disk								
	B.	D.	P.	Sp.	% $\Delta$	B.	D.	P.	Sp.	% $\Delta$	B.	D.	P.	Sp.	% $\Delta$	B.	D.	P.	Sp.	% $\Delta$	
25	3.6		2.9	40										8.4	7.1	10					
50	5.7		4.3	30		6.5		4.7	15		1.2		8.1	15		12.2		8.2	15		
75						8.9		6.2	30												
100	13.2		7.6	40		14.5		7.4	40		17.8		13.5	10		16.0		11.8	8		
150	19.5		11.1	30		19.1		11.1	40		22.1		16.3	8							
175																19.7		14.7	5		
200	27.2		15.3	15		27.9		22.1	20		24.4		18.7	6							
250											26.7		20.4	8		23.3		17.4	6		

TABLE 4.—DIELECTRIC STRENGTHS OF FOUR U. S. A. TRANSFORMER OILS (1)

Parallel tests by Vacuum Oil Co. (Vac.), Westinghouse Electric and Manufacturing Co. (W), and National Bureau of Standards (B. S.). Most accurate data available. Each number is average of 15 observations; individual deviation from mean = 10 %, the same in all cases.

Unit of  $D$  and  $G = 1$  in. = 2.54 cm.  $V = 1$  sec by S. U. at 0°C.

Elec- trodes	Gap $G$	Breakdown values, effective (r. m. s.) kilovolt, 60 cycles, 25°C							
		B. S.	Vac.	W	Mean	B. S.	Vac.	W	Mean
		A ( $d = 0.854$ , $V = 55$ )				B ( $d = 0.867$ , $V = 100$ )			
Disks $D = 1$	0.05	15.2	11.7	18.0	15.0	15.2	8.9	14.3	12.8
	0.10*	23.6	23.2	35.8	27.5	26.5	22.3	30.5	26.4
	0.15	33.6	32.9	39.3	35.3	36.3	32.2	42.8	37.1
	0.20	40.6	39.1	53.8	44.5	42.8	37.6	55.7	45.4
Disks $D = 0.5$	0.05	21.2	15.3	22.2	19.6	21.5	13.2	20.9	18.5
	0.10	37.9	29.4	38.9	35.4	37.1	24.8	38.7	33.5
	0.15	48.7	38.9	47.5	45.0	47.9	33.4	42.8	41.4
	0.20	49.3	45.2	51.0	48.5	49.8	46.1	54.9	50.3
Spheres $D = 0.5$	0.05	23.6	23.6	29.5	25.6	22.6	20.7	25.3	22.9
	0.10	44.2	45.5	51.1	46.9	38.5	35.2	48.6	40.8
	0.15	61.1		67.1	64.1	56.0	51.1	60.6	55.9
	0.20	68.9			68.9	70.5			70.5
		C ( $d = 0.829$ , $V = 34$ )				D ( $d = 0.860$ , $V = 74$ )			
Disks $D = 1$	0.05	16.5	8.8	18.5	14.6	16.8	11.0	17.8	15.2
	0.10*	33.5	25.9	40.7	33.4	29.1	24.6	37.8	30.5
	0.15	39.5	32.5	53.7	42.0	38.5	30.9	48.7	39.4
	0.20	50.8	39.8	64.8	51.8	41.2	37.9	59.8	46.3
Disks $D = 0.5$	0.05	27.1	20.0	24.9	24.0	25.8	14.0	19.4	19.7
	0.10	48.4	34.6	42.9	42.0	41.0	26.9	40.7	36.2
	0.15	48.8	42.3	57.9	49.7	54.3	33.7	47.0	45.0
	0.20	60.0	50.6	67.4	59.3	55.5	42.5	52.8	50.3
Spheres $D = 0.5$	0.05	33.4	26.3	32.9	30.8	26.2	22.5	30.0	26.2
	0.10	49.1	50.2	55.3	51.5	50.1	43.8	56.4	50.1
	0.15	67.1			67.1	61.1	52.4	56.7	56.7
	0.20					72.5			72.5

\* This is the standard gap recommended by American Society for Testing Materials (1)—1 in. flat disks with square shoulders, spaced 0.1 in. apart. For this gap, the B. D. value for transformer oils should lie in the range 26.4 to 33.4 kilovolt.

TABLE 5.—RELATIVE BREAKDOWN VOLTAGES FOR THREE COMMERCIAL TEST GAPS (1)

(Voltage, gap  $E_1$ )/(voltage, gap  $E_2$ )

Unit of  $D$  and  $G = 1$  in. = 2.54 cm.

$E_1$	A	B	C
A	1.00	1.80	2.05
B	0.55	1.00	1.20
C	0.50	0.85	1.00
	Disk	Disk	Sphere
$D$	1	0.5	0.5
$G$	0.1	0.2	0.15

TABLE 6.—ERROR IN THE AVERAGE OF  $n$  TESTS OF DIELECTRIC STRENGTH OF AN OIL

Based on 3000 tests (6, 7)

Unit of error = 1 %.

$n$	Error	Sphere long*	Sphere short*	Point, sphere
1	Av.	7.8	7.8	8.4
1	Max.	48.5	34.1	44.8
3	Av.	5.2	4.9	4.9
3	Max.	22.4	19.7	19.1
6	Av.	2.7	3.5	4.1
6	Max.	17.5	15.0	14.3

\* Average: Long = 27 mm; short = 2 mm.

TABLE 7.—SPARKOVER VOLTAGE BETWEEN CONCENTRIC CYLINDERS (14)

For  $\frac{R}{r} > 3.5$  corona appears in transformer oils before sparkover occurs; for  $\frac{R}{r} < 3.5$ , the sparkover and corona voltages are the same and obey the relation:  $g = 36 \left( 1 + \frac{1.2}{\sqrt{r}} \right)$ .  $g$  = maximum voltage gradient at surface of electrode, in kilovolt/cm;  $R$ ,  $r$  = radius of outer, inner, cylinder in cm;  $g_o$ ,  $g_c = g_x$  observed,  $g$  computed. The \* denotes where  $R/r$  becomes less than 3.5.

Unit of  $r = 1$  cm; of P. D. = 1000 volt; of  $g = 1000$  volt/cm ( $R = 3.81$  cm).

$r$	P. D., max.	$g_o$	$g_c$
0.238	84.0	127.7	123.8
0.317	85.5	108.1	112.7
0.635	98.3	86.3	90.3
0.794	106.1	85.5	84.6
0.952	103.2	78.1	80.2
1.111*	108.5	79.4	76.9
1.270	107.5	77.0	74.3
1.587	104.3	75.1	70.4
1.905	93.7	70.7	67.2
2.540	64.3	62.4	63.1

TABLE 8.—INFLUENCE OF MOISTURE ON DIELECTRIC STRENGTH Kilovolt (kv) for breakdown; disks,  $D = 0.5$  in.,  $G = 0.2$  in.; temp. 25°C; U. S. A. Oil F (13, 14)

Water, volume in 10 000.....	0	0.5	1.0	2.0	5.0	10.0
Kv, 60 cycles, maximum.....	62.3	33.5	33.4	31.7	27.3	25.4
Kv, constant voltage.....	61.5	34.7	34.3	30.2	24.7	23.0

Ryan (17), Tobey (23), Peek (13, 14, 15), and others (11, 16, 2) show that moisture in very small quantities decreases the dielectric strength of insulating oil.

Hirobe (8), McLaughlin (9), Stern (22), Spath (21), and Schroter (19) agree experimentally that moisture has little effect on the dielectric strength of the purest oils. The potent causes of low dielectric strength are fibers and dust particles in the oil.



Their effect is increased by the presence of moisture (*cf.* Table 9). For methods and effect of cleaning electrodes, *see* (8).

TABLE 9.—DIELECTRIC STRENGTH: EFFECT OF CLEANING AND DRYING THE OIL (19)

$F$  = effective field strength at which breakdown occurs  
Unit of  $F$  = 1000 volt/cm; of  $\% \Delta$  = 1 %.

Condition of oil*	$F$	$\% \Delta$
As delivered.....	48.5	75
Filtered through 4 mm clay wall.....	115.0	50
Centrifuged.....	124.0	30
Filtered through ordinary filter paper.....	163.0	35
After prolonged drying by heat.....	184.0	40
Prolonged drying by heat and filtered once through celloid filter.....	232.0	8
As in preceding, but filtered twice.....	332.0	7

\* Each line of the table is complete in itself; tests were not successive.

TABLE 10.—RESISTIVITY ( $R$ ) AND DIELECTRIC STRENGTH ( $S$ ) OF DRY OIL: VARIATION WITH TEMPERATURE (23)

$R$  is expressed in terms of the resistance between disks,  $D = 4$  in.,  $G = 0.44$  in.;  $S$  in terms of the effective breakdown P. D. between spheres,  $D = 0.5$  in.,  $G = 0.15$  in. Approximately  $S = S_{25} - 0.13(t - 25^\circ)$  kilovolt (1);  $t$  = temperature,  $^\circ\text{C}$ ;  $S_{25}$  = value of  $S$  at  $25^\circ\text{C}$ .

Unit of  $S$  = 1000 volt; of  $R = 10^6$  ohm; of  $t = 1^\circ\text{C}$ .

Temperature ( $t$ )	30	40	50	60	70	80	$90^\circ\text{C}$
Strength ( $S$ ).....	33	35	36	37	38	39	41
Resistivity ( $R$ ).....			1225	960	570	360	250

#### LITERATURE

(For a key to the periodicals see end of volume)

- (1) Silsbee, 66, 21: 397; 21. (2) Armstrong, 107, 62: 1322; 13. (3) Digby and Mills, 46, 28: 769; 09. (4) Crussard, 106, 13: 443; 23. (5) Everest, 121, 87: 702; 21. (6) Hayden and Eddy, 129, 41: 102; 22. (7) Hayden and Eddy, 129, 41: 394; 22. (8) Hirobe, *Elect. Technical Laboratory Report*, No. 25: Sect. 3 (Japan). (9) McLaughlin, 121, 86: 325; 21. (10) Moody, W. S., General Electric Co., Schenectady, New York, O. (11) Moody and Faccioli, 129, 28: 769; 09. (12) National Electric Light Association, *Bulletin*, June, 1910. (13) Peek, 129, 35 II: 783; 16. (14) Peek, 120, 18: 821; 15. (15) Peek, *Dielectric Phenomena in High Voltage Engineering*, Chap. IV. New York, McGraw-Hill Book Company, Inc., 1915. (16) Rodman, 114, 20: 51; 23. (17) Ryan, 129, 30: 1; 11. (18) Schendell, 101, 37: 242; 18. (19) Schroter, 125, 12: 67; 23. (20) Skinner, C. E., Westinghouse Electric and Manufacturing Co., East Pittsburgh, O. (21) Spath, 125, 12: 331; 23. (22) Stern, 101, 43: 140; 22. (23) Tobey, 129, 29 II: 1189; 10. (24) Tesche, 97, 5: 233; 24. (25) Wedmore, 121, 87: 702; 21.

#### INSULATING SOLIDS

F. MALCOLM FARMER

Because of inherent variations in composition and physical condition of both manufactured and natural products, no single value can be assigned to any of the various properties of solid electrical insulators. Furthermore, the value obtained in the measurement of many electrical properties depends upon the method employed and the conditions under which the test was made. For example, in determinations of either the volume or the surface resistivity, the result will depend upon the voltage employed, the duration of its application, temperature, humidity, etc. No standard procedure has yet been established for determining the various quantities. The available data have been obtained under a great variety of conditions and with many different procedures (which, in most cases, are not fully stated) so that the selection of values for these tables has been a matter of judgment, the aim being to select those values which it is believed are most typical and, consequently, the most reliable for general application. Some of the principal sources from which data have been obtained are named on p. 311. Discussions of some of these variable factors will be found in (1, 3, 9); for bibliographies, *see* (2, 18, 19).

Par suite des variations inhérentes à la composition et aux conditions physiques des produits manufacturés et naturels, il n'est possible d'assigner une valeur unique à aucune des propriétés variées des isolants électriques solides. De plus, les valeurs obtenues par les mesures de plusieurs propriétés électriques dépendent de la méthode employée et des conditions dans lesquelles l'essai a été effectué. Par exemple, dans les déterminations de la résistivité du volume et de la résistivité superficielle, le résultat dépend du voltage employé, de la durée de l'application, de la température, de l'humidité, etc. Aucune procédure type n'a encore été établie pour déterminer les quantités variées. Les données disponibles ont été obtenues suivant une grande variété de conditions et avec des procédures différentes (qui, dans la plupart des cas, ne sont pas complètement spécifiées); de sorte que la sélection des valeurs pour ces tables a été une question de jugement, l'objectif étant de choisir celles des valeurs qui étaient présumées les plus typiques et par conséquent les plus dignes de confiance pour l'application générale. Quelques unes des sources principales dont ont été tirées les valeurs sont indiquées à la page 311. On trouvera les discussions relatives à quelques uns des facteurs variables à (1, 3, 9); en ce qui concerne la bibliographie, voir (2, 18, 19).

Entsprechend der eigenartigen Änderung in der Zusammensetzung und des physikalischen Zustandes der festen Isolatoren, kann man sowohl den künstlichen als auch den natürlichen Produkten keinen einzelnen Wert ihrgegend welcher der verschiedenen Eigenschaften zu ordnen. Es hängt ferner der gemessene Wert vieler elektrischer Eigenschaften von der angewandten Methode und den Bedingungen unter welchen die Probe ausgeführt worden ist, ab. Z. B. bei der Bestimmung des Oberflächen Widerstandes wird das Ergebnis von der angewandten Volt-Zahl, der Dauer der Einwirkung, der Temperatur, der Feuchtigkeit u. s. w. abhängen. Bis jetzt ist keine diesbezügliche Standardmethode zur Messung der verschiedenen Grössen aufgestellt. Die erreichbaren Daten sind unter den verschiedenen Bedingungen und sehr verschiedenen Prüfungsvorgängen (die in vielen Fällen auch nicht ganz angegeben sind) erhalten. Es ist deshalb diese Auswahl nach besonderem Urteil gemacht worden, mit dem Ziel im Auge, diejenigen Werte herauszugreifen, die man als die typischsten ansieht und demzufolge allgemein am zuverlässlichsten sein werden. Einige der hauptsächlichsten Quellen aus denen die Werte geschöpft wurden sind Seite 311 angegeben. Zur Diskussion einiger der veränderlichen Faktoren, (1, 3, 9), Literatur dazu, siehe (2, 18, 19).

A causa di alterazioni nella composizione e nello stato fisico sia dei prodotti artificiali che naturali, non si può assegnare un valore determinato alle varie proprietà degli isolanti elettrici solidi. Inoltre, il valore ottenuto nella misura di molte proprietà elettriche dipende dal metodo impiegato e dalle condizioni nelle quali la prova è stata fatta. Per esempio, quando si determina la resistività di volume o di superficie, il risultato dipende dal voltage adoperato, dalla durata di applicazione, dalla temperatura, dalla umidità, ecc. Non è stata ancora stabilita una procedura uniforme per determinare le varie grandezze.

I dati disponibili sono stati ottenuti in condizioni molto diverse e con metodi differenti (il più delle volte neppure completamente indicati); per modo che la scelta dei valori per queste tabelle è stata fatta con un certo arbitrio e con lo scopo di raccogliere i valori ritenuti più tipici e quindi suscettibili di una più generale applicazione.

Alcune delle fonti principali dalle quali i dati sono stati tratti sono indicate a pag. 311. Per la discussione di alcuni dei fattori variabili si veda (1, 3, 9) e per le indicazioni bibliografiche si veda (2, 18, 19).



## Manufacturers Mentioned in this Section

M1	Alberene Stone Company, New York, N. Y.
M2	Chicago Mica Company, Chicago, Ill.
M3	Continental Fibre Company, Newark, Del.
M4	Electrose Manufacturing Co., Brooklyn, N. Y.
M5	Garfield Manufacturing Co., Garfield, N. J.
M6	General Electric Co., Schenectady, N. Y.
M7	General Insulate Co., Brooklyn, N. Y.
M8	Hemming Manufacturing Co., Garfield, N. J.
M9	Irvington Varnish and Insulator Co., Irvington, N. J.
M10	Mica Insulator Co., Schenectady, N. Y.
M11	Minerallac Electric Co., Chicago, Ill.
M12	Mitchell-Rand Mfg. Co., New York, N. Y.
M13	National Vulcanized Fibre Co., Wilmington, Del.
M14	Spaulding Fibre Co., Inc., Tonawanda, N. Y.
M15	D. M. Stewart Manufacturing Co., Chattanooga, Tenn.
M16	Westinghouse Electric and Manufacturing Co., East Pittsburgh, Pa.

TABLE 1.—INDEX AND DESCRIPTION OF MATERIALS

Glass, *v.* p. 87, porcelain, *v.* p. 66, rubber and rubber products, *v.* p. 254, phenol condensation products, *v.* p. 296

## I. Bituminous, Wax and Molded Materials

INDEX  
No.

- 1. Ambrion.**—A molded product (German). Asbestos, impregnated with a pitch or rosin binder. Several grades—some fireproof, some limited to 80 to 100°C.
- 2. Asphalt.**—Various grades known as bitumen, byerlite, elaterite, gilsonite, manjak, and mineral pitch. A black, natural product found in various parts of the world. Used extensively as base for insulating varnishes, for impregnating insulating materials, and (in Europe) for insulating wires and cables (instead of rubber). Hard at ordinary temperatures, plastic at 40–60°C, melts at 100–200°C, depending upon purity.
- 3. Beeswax.**—The secreted substances of which the bee's honeycomb is constructed; yellow; agreeable odor and taste. Solid at ordinary temperatures, plastic when warm, melts at 62–64°C.
- 4. Ceresin.**—A yellow or white wax made by purifying and bleaching ozokerite (*see* 10). Used extensively in manufacture of insulating compounds.
- 5. Electrose.**—Trade name for a product manufactured and molded by M4; working temperature limit, about 90°C.
- 6. Gummon.**—Trade name for a coal tar and asbestos product manufactured and molded in desired shape by M5. Black, hard, dense, not easily drilled or sawed, can be highly polished, and will withstand 200°C indefinitely.
- 7. Hemit.**—Trade name for a coal tar and asbestos product manufactured and molded in desired shape by M5. Hard, dense, not easily drilled or sawed; withstands temperature of 600 to 800°C. Grade "B" is gray and hygroscopic; grade "A" is impregnated, making it black and more nearly waterproof.
- 8. Insulate.**—Trade name for a mineral product manufactured and molded in desired shape by M7. Non-hygroscopic; maximum working temperature, 70°C.
- 9. Minerallac.**—Trade name for asphaltic base insulating material manufactured by M11 in various grades for different applications (principally cable joints, cable terminals, etc.). Some grades semi-liquid, others semi-solid at 25°C. Moisture-proof.
- 10. Ozokerite** (*See* Ceresin).—A natural, mineral wax material, usually associated with rock salt or gypsum; found throughout the world, but principally in Galicia. Is probably

paraffin resulting from natural decomposition of petroleum. Natural color brown or black, but white when purified; melts at 110°C.

- 11. Paraffin.**—Translucent, more or less colorless wax material obtained in the distillation of petroleum. Various commercial grades; melts at 45 to 80°C, depending upon grade; unaffected by ordinary acids and alkalies.
- 11(a). Petrolatum.**—A neutral and purified residue derived by distillation of petroleum. Three forms—liquid, soft, and hard. The soft form is a grease similar to vaseline and is used extensively as an impregnating material for paper insulated cables; melts about 50–55°C; electrical properties vary greatly with the purity.
- 12. Rosin.**—A variety of resin. Product of distillation of oil of turpentine from crude turpentine.
- 13. Tegit.**—Trade name for a coal tar and asbestos product manufactured and molded in desired shape by M8. Uses limited to 200°C.

## II. Fibrous Materials and Fiber Products

- 14. Cellulak.**—Trade name for laminated paper insulation manufactured by M9. Processed under heat and pressure. Hard, tough, readily machined.
- 15. Cellulose.**—A carbohydrate similar in chemical composition to starch. When pure, is amorphous and white; is basis of practically all fibrous insulating materials. Unsized, well bleached linen paper is practically pure cellulose.
- 16. Conite.**—(*See* 18.) Trade name for a thin, hard, vulcanized fiber prepared by M3 with special care to insure its freedom from acid.
- 17. Empire Cloth.**—Trade name of M10 for various varnished cloths having coatings of linseed-oil base (*see* 29).
- 18. Fiber, Vulcanized.**—Also known as fiber, horn fiber, hard fiber, indurated fiber, leatheroid, etc. Made by treating layers of paper stock made from pure cotton cellulose (old cotton rags free from dirt, oil, and grease) with concentrated acids or zinc chloride. Compressed under great pressure to desired thickness; soaked and washed in water for long periods to remove acid or chloride; air dried, pressed in steam-heated presses and calendered to final thickness. Hard, tough, bone-like, hygroscopic, absorbs water readily, disintegrates with strong acids, unaffected by organic solvents and oils, becomes brittle at 80 to 100°C sustained temperature, readily machined, various colors. Manufactured by M3, M13, M14, and others.
- 19. Fish Paper.**—Also known as tarpon paper, leather paper, leatheroid, and fiberoid. Prepared in similar manner to vulcanized fiber using cotton rag stock. Flexible; dark gray; thickness about 0.1 to 1.2 mm.
- 20. Kobak Cloth.**—Trade name (M10) for black varnished cambric (*see* 28).
- 21. Kraft Paper** (For cables).—Unsized paper made from wood pulp stock by sulfate process (21a). Hygroscopic. Used extensively in Europe in high tension power cables where it is impregnated with an insulating material (21b) after application to conductors.
- 22. Manila Paper** (For cables) (*See* 26).—Unsized paper made from old manila rope (22a). Used extensively in America on high tension power cables where it is impregnated with an insulating material (22b) after application to conductors.
- 23. Paraffined Paper.**—Bond paper coated or saturated with hot paraffin. Used extensively in low voltage electric condensers.
- 24. Pressboard.**—Also known as fullerboard and presspan (in Europe). A high grade cardboard paper made from cotton rag and paper clipping stock. Hygroscopic.



25. **Pressboard, Treated.**—Pressboard dried (sometimes in vacuum) and varnished (25a) or boiled in mineral oil (25b) to make it moisture-proof and to increase dielectric strength.
26. **Rope Paper** (See 22).—Paper made from old rope stock (hemp and jute). Compressed but unsized. Hygroscopic.
27. **Varnished Cloth** (See 17, 20, 28, 29, 30, 31 and 33).—Also known as treated cloth. Thin cotton, linen, or silk cloth dried and coated with various thicknesses of various kinds of liquid insulating materials so applied and treated as to produce a smooth, sheet insulating material which is flexible, tough, and uniform in thickness. Great variety manufactured (some under trade names) by M6, M9, M10, M12, M16, and others.
28. **Varnished Cambric, Black** (See 27).—Coated with an asphaltic material and an oxidizing oil. Black, oil-proof, but not moisture-proof; is more flexible, and remains flexible longer, than the yellow cambric; is, also, more resistant to action of corona discharge (*i.e.*, ozone and nitric acid). Thickness, 0.1 to 0.4 mm.
29. **Varnished Cambric, Yellow** (See 27).—Also known as varnished muslin, oiled cambric and oiled muslin. Coated with linseed oil and a resin; filler is yellow and translucent; absorbs moisture, but is oil-proof. Thickness, 0.1 to 0.4 mm.
30. **Varnished Duck or Canvas, Black.**—Same as black varnished cambric except that the base is duck or canvas. Thickness, 0.4 to 0.8 mm.
31. **Varnished Duck or Canvas, Yellow.**—Same as yellow varnished cambric except that the base is duck or canvas. Thickness, 0.4 to 0.8 mm.
32. **Varnished Paper.**—Paper [cotton (bond), linen, and hemp (manila) stock papers, also fish paper] treated like varnished cloth. Treatment greatly increases resistance to moisture absorption and increases dielectric strength (*ca.* 25%).
33. **Varnished Silk.**—Same as yellow varnished cambric except that base is silk. Thickness, 0.05 to 0.2 mm.
34. **Woods, Hard.**—Maple, hickory, cherry, ash, and yellow pine principally used. Dried (34a) and impregnated with oil (34b), paraffin (34c) or rosin, either by boiling until evolution of gas ceases or by impregnation under pressure after drying *in vacuo*.

### III. Mineral Materials

35. **Alberene** (See soapstone, 47).—A fine grade of natural soapstone uniformly gray in color, free from metallic veins. Marketed by M1. Does not split or shale under intense local heating, such as electric arc. Stated to be capable of withstanding 1300 to 1600°C. Soft, easily machined, sawed, and drilled.
36. **Asbestos Paper.**—Soft, flexible sheet material made from fibrous asbestos with 15 to 20% cotton. Very hygroscopic.
37. **"Lava."**—A form of talc (hydrated magnesium silicate), similar to pumice, which, while in its natural state, is formed or machined to desired shape and then baked at 1100°C, making it very hard. It is then not affected by any lower temperature; very porous, but dimensions not affected by absorption of water; slightly affected by HCl, but not by other ordinary acids and alkalis; very light yellow.
38. **Lavite.**—Trade name for patented product manufactured by M15. Similar to "lava." Compares with glass in hardness; unaffected by temperatures up to 1000°C, or by ordinary acids or alkalis; porous; very light yellow.
39. **Marble.**—Crystalline limestone which takes a high polish. Pure marble is white; colored marbles contain impurities, such as iron oxide. Much used for electrical switchboards where, because of porosity, it is frequently impregnated

with insulating material to increase dielectric strength; often stained black (called marine finish) to prevent discoloration due to oil staining, etc.

40. **Mica.**—A laminated mineral composed of crystallized anhydrous silicate of aluminum and potash, or soda. Pure mica is transparent, but frequently colored by salts deposited between laminations. Laminations easily separated so that mica can be split down to 0.005 mm. In natural state it is not uniform in quality, is not flexible, and largest pieces are relatively small; hence it is reconstructed, by splitting into thin laminations and cementing together the small pieces, with suitable binders, to form continuous sheets of various thicknesses, which are marketed under trade names (*see* 41 to 45 *inc.*). Powdered and flaked mica is used in conjunction with suitable binders to make molded insulations (a substitute for hard rubber, etc.). Properties vary considerably with impurity content, and with sources from which obtained, the principal of which are India, Africa, Canada, and United States. The clear variety has highest dielectric strength.
41. **Mica Cloth.**—Reconstructed mica (*see* 40) with special binder and backed with cloth. Flexible (to various degrees); thickness, 0.1 to 3 mm.
42. **Mica Bond.**—Trade name for mica cloth, mica paper, and mica plate products manufactured by M2 (*see* 41, 43 and 44).
43. **Mica Paper.**—Reconstructed mica (*see* 40) with special binder and backed with Japanese paper. Flexible; thickness, 0.25 to 0.5 mm.
44. **Mica Plate.**—Reconstructed mica (*see* 40) with shellac binder. Not flexible; thickness, 0.25 to 3 mm.
45. **Micanite.**—Trade name for mica cloth, mica paper, and mica plate products manufactured by M10 (*see* 41, 43, 44).
46. **Slate.**—Natural rock of clay or mica composition with natural cleavage. Formed by geological processes involving high temperature and pressure. Principal components are silica and alumina with some iron oxides, lime, magnesia, potash, and soda. Slate for electrical purposes is principally the mica variety from Vermont (purple to green), Maine, and Pennsylvania; the last two are dark gray (called black slate). Is hygroscopic and contains relatively large amount of water of composition, hence thorough drying followed by oil treatment or coating with insulating varnish or enamel greatly improves insulating value. Easily machined; takes good polish.
47. **Soapstone** (See Alberene, 35).—A natural, soft stone; a variety of talc. (Also called steatite.) Slightly soapy or oily to touch. Easily machined, drilled, and sawed. Hygroscopic. Withstands temperatures of the order of 1500°C.

### IV. Gum Materials

48. **Amberite.**—(Ambroid.) Compressed scrap amber (fossilized vegetable resin). Equal to native amber in volume resistivity, but surface must be kept clean for high surface resistivity.
49. **Copal.**—A resinous substance which, when dissolved in alcohol, oil of turpentine, or linseed oil, makes a colorless varnish. Very inflammable; brittle when cold.
50. **Shellac.**—A crude form of lac, a resinous gum exuded by an East Indian insect, also obtained from sap of certain trees. Shellac dissolved in alcohol is extensively used as an insulating varnish which on drying forms hard, protective coating. Brittle, brown, hygroscopic.

### V. Miscellaneous Materials

51. **Enamel.**—A hard, smooth, and flexible coating baked on magnet wire as substitute for cotton and silk, or in addition thereto. Composition more or less a manufacturing secret,

but stated in some cases to be stearin pitch, cellulose acetate, or cellulose nitrate. Applied by running wire through thin bath and rapidly drying each coat by passing through hot oven. Occupies less space than cotton and silk, has greater thermal conductivity; moisture-proof and mineral oil-proof, but more or less soluble in vegetable oil, animal oil, alcohol, turpentine, and coal tar solvents; withstands 100°C indefinitely; breaks down electrically at 300°C.

**52. Galalith.**—German product manufactured from skim-milk heated with caustic soda and precipitated with acid. The precipitate, in sheet and plate form, is dried, saturated with formaldehyde, and again dried and pressed. Used as substitute for ivory. Translucent and yellowish white; readily shaped, after softening in hot water; rather hygroscopic.

**53. Ivory.**—Tusks of the elephant, walrus, etc. Hard and white.

TABLE 2.—ELECTRICAL PROPERTIES

Volume resistivity (*see* Vol. I, p. 41) =  $R_v \times 10^n$ . Surface resistivity (*see* Vol. I, p. 41) =  $R_s \times 10^n$ . Power factor =  $\cos \varphi$ . Temperature = 18 to 25°C except as indicated. Unit of:  $R_v = 1$  ohm-cm;  $R_s = 1$  ohm; frequency = 1 cycle/sec; dielectric constant = 1 cgse (essentially, air = 1); thickness = 1 mm.

Index No.	Material	Resistivity				Dielectric constant		Dielectric strength		Power factor	
		$R_v$	$n$	$R_s$	$n$	Frequency	Constant	Thickness	Kv/mm	Frequency	$\cos \varphi$
35	Alberene.....	( <i>See</i> Soap-stone)									
48	Amberite (ambroid).....	5	16	2	15		2.8*				
1	Ambrion.....	2	13					0.8	6		
36	Asbestos paper.....	2	5					1.0	4		
2	Asphalt.....						2.7	2.0 to 3.0	1 to 2		
3	Beeswax.....	5 to 20†	14	8	14§		1.85		10		
14	Cellulak.....							3.0	16		
15	Cellulose.....	1	9				3.9 to 7.5				
4	Ceresin.....	5	18	8	16						
16	Conite.....							0.12	15		
49	Copal.....							3.0	3		
5	Electrose.....	1 to 15	14	1 to 1000	12			3.0	25		
51	Enamel.....	1	14					0.02	20 to 25		
18	Fiber, vulcanized.....	5 to 20	9	1	10	90 to 650‡	5.0 to 7.5	1.0	8 to 18	90 to 650‡	0.045
								3.0	5 to 12		
								6.0	4 to 9		
								12.0	3 to 6		
19	Fish paper.....							0.1 to 1.2	10 to 15		
52	Galalith.....	1	10	6	10				6 to 8.5		
6	Gummon.....	3	12	3	12				3		
7	Hemit.....	1	10	1	10				2		
8	Insulate (No. 2).....	8	15	4	14			10	1.5 to 2		
53	Ivory.....	2	8	6	9						
21a	Kraft paper.....							0.15 to 0.2	4 to 6		
21b	Kraft paper.....					60	3.5	0.15 to 0.2	30 to 40	60	0.005
37	"Lava".....								3 to 10		
38	Lavite.....	5 to 25	8	1	11				8 to 10		
22a	Manila paper.....					920 to 4600	2.0	0.15 to 0.2	3 to 5	920 to 4600	0.007 to 0.008
22b	Manila paper.....	2	9			60	3.5	0.15 to 0.2	20 to 30	60	0.005
34b	Maple, oiled.....							25	3.0		
34c	Maple, paraffined.....	3	10	8	11		4.1	15	4.5		
39	Marble.....	1 to 100	9	6	9	60	8.3	25	2 to 4	90 to 650	0.003 to 0.05
						90 to 650‡	9.5 to 11.5				
40	Mica.....	1 to 200	15	1 to 3000	10		4.5 to 7.5	0.05	80 to 200	800	0.001 to 0.07
								0.3	40 to 120		
								0.6	25 to 75		
41, 43	Mica, cloth and paper.....							0.1 to 3	40 to 15		
44	Mica plate.....							0.1 to 3	50 to 25		
9	Minerallac.....					60	2.7	0.5	40		
10	Ozokerite.....	5	14				2.2	0.6	45		
11	Paraffin.....	1 to 500	16	1†	16		1.9 to 2.3		15 to 50		
23	Paraffined paper.....								40 to 60		
11a	Petrolatum.....	2 to 10	12			60	2.2	2.5	20	60	0.005
24	Pressboard.....	1	9					0.2 to 3.0	12 to 5		
25a	Pressboard.....						2.9	0.5 to 3.0	15 to 10		
25b	Pressboard.....						4.5	0.5 to 3.0	30 to 20		
12	Rosin.....	5	16	7	14		2.5				
50	Shellac.....	1	16	7	13		2.7 to 3.7				
46	Slate.....	1	8	1	8		6.0 to 7.5	25	0.2 to 0.4	950	0.086
47	Soapstone.....	6	8					25	1.0		
13	Tegit.....	2	12	7	11				2		
28	Varnished cambrie b.....							0.1 to 0.4	70 to 50		
29	Varnished cambrie y.....						3.5 to 5.5	0.1 to 0.4	60 to 45		
30	Varnished canvas b.....							0.4 to 0.8	12 to 30		
31	Varnished canvas y.....							0.4 to 0.8	25 to 10		
32	Varnished paper.....								10 to 25		
33	Varnished silk.....							0.05 to 0.2	70 to 45		
34a	Woods, hard, dried.....	1 to 4000	10			90 to 650‡	3.0	25	0.4 to 0.6	90 to 650‡	0.025

\* Amber.

† Has very large negative temperature coefficient,  $R_v$  at 30° being about  $\frac{1}{16}$  of that at 90°C.

‡ Kilocycles.

§ Fresh surface. Deteriorates rapidly.



TABLE 3.—MECHANICAL AND THERMAL PROPERTIES 18 TO 25°C

Unit of: density = 1 g/cm<sup>3</sup>; strength = 1 kg/cm<sup>2</sup> (for Nos. 21, 22, 28 to 33 = 1 kg per cm width); expansivity = 10<sup>-4</sup> per °C; thermal conductivity = 1 milliwatt per (cm °C).

Index No.	Material	Density	Strength		Cubic expansivity	Thermal conductivity
			Tensile*	Compressive		
1	Ambrion.....	1.4 to 1.8	150	190		
36	Asbestos paper.....	3.2				2.5
2	Asphalt.....	1.04 to 1.40			5 to 7	
3	Beeswax.....	0.96				0.35
4	Ceresin.....	0.75				
16	Conite.....		550 to 1100			
18	Fiber, vulcanized.....	1.2 to 1.5	625 to 1050	1800 to 3200	0.27	
52	Galalith.....	1.3				
6	Gummon.....		40	40		
7	Hemit.....		140	110		
53	Ivory.....	1.9				
21a	Kraft paper.....	0.8	500 to 700†			
21b	Kraft paper.....		400 to 500†			
37	"Lava".....	2.5 to 2.7		1400 to 2100	Negligible	8
38	Lavite.....	2.5 to 2.7	400 to 800‡	1400 to 2100		
22a	Manila paper.....	0.8	700†			1.2
22b	Manila paper.....		500†			1.7
39	Marble.....	2.5 to 2.8	100 to 200‡	600 to 1500	0.3 to 0.6	30
40	Mica.....	2.7 to 3.1				3.6
41, 43	Mica, cloth and paper.....					1.0 to 1.6
9	Minerallac.....	1.0			7	
11	Paraffin.....	0.87 to 0.94			3 to 6	2.6
25a	Pressboard.....					1.4
50	Shellac.....					2.5
46	Slate.....	2.7 to 2.9	550 to 700‡	700 to 1000	0.15 to 0.3	20.0
47	Soapstone.....	2.6 to 2.8		550		
13	Tegit.....		85	80		
28, 29	Varnished cambric.....		8 to 10§			2.5
30, 31	Varnished canvas.....		10 to 20§			
33	Varnished silk.....		2 to 3§			
34	Woods, hard, dried.....	0.6 to 0.9	500 to 1000	250 to 550	0.1 to 2.0	1.5 to 2.5

\* For Nos. 38, 39, 46 data are for transverse strength, as noted.

† In machine direction (i.e., lengthwise of majority of fibers). Strength crosswise about half as great.

‡ Modulus of rupture (transverse strength)—probably somewhat higher than tensile strength.

§ Kg per cm of width. Stress in direction of warp. About half as strong when stress is in direction of filler.

## LITERATURE

(For a key to the periodicals see end of volume)

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## THERMAL INSULATING MATERIALS FOR MODERATE AND LOW TEMPERATURES

F. H. SCHOFIELD AND J. A. HALL

This section covers the various types of commercial insulating materials, associated structural materials and some miscellaneous materials. For the second group of materials reference should also be made to the sections of I. C. T. dealing with these classes of materials.

In the tables below the various materials are assembled in groups which are arranged approximately in the ascending order of the lowest thermal conductivity of any material of the group.

The thermal conductivity,  $k$ , is given in  $10^{-3}$  joule  $\text{cm}^{-2} \text{sec}^{-1} (^\circ\text{C}, \text{cm}^{-1})^{-1}$ , one unit of which =  $0.239 \times 10^{-3}$  g-cal  $\text{cm}^{-2} \text{sec}^{-1} (^\circ\text{C}, \text{cm}^{-1})^{-1}$ , =  $0.192 \times 10^{-3}$  BTU  $\text{ft}^{-2} \text{sec}^{-1} (^\circ\text{F}, \text{in.}^{-1})^{-1}$ . See also vol. I, p. 25 for other conversion factors.

Cette section comprend les types variés des matières isolantes du commerce, les matériaux de construction associés, et quelques matières diverses. En ce qui concerne le deuxième groupe de matières, il faut aussi consulter les sections des I. C. T. qui traitent de ces classes de matières.

Dans les tables ci dessous, les matières variées sont arrangés en groupes approximativement dans l'ordre ascendant de la conductibilité thermique la plus basse du groupe.

La conductibilité thermique,  $k$ , est donnée en  $10^{-3}$  joule  $\text{cm}^{-2} \text{sec}^{-1} (^\circ\text{C}, \text{cm}^{-1})^{-1}$ , une unité de celle-ci =  $0,239 \times 10^{-3}$  g-cal  $\text{cm}^{-2} \text{sec}^{-1} (^\circ\text{C}, \text{cm}^{-1})^{-1}$ , =  $0,192 \times 10^{-3}$  BTU  $\text{ft}^{-2} \text{sec}^{-1} (^\circ\text{F}, \text{in.}^{-1})^{-1}$ . Voir vol. I, p. 25 pour d'autres facteurs de conversion.

Dieser Abschnitt behandelt die verschiedenen Typen von handelsüblichen Isoliermaterial, damit zusammenhängendem Material und einigem verschiedenen anderen. Für die zweite Gruppe der Materialien soll auch in dem Teil der I. C. T. nachgeschlagen werden, die diese Klasse von Materialien behandeln.

In der unteren Tafel sind die verschiedenen Materialien in Gruppen angeordnet und zwar ansteigend von dem kleinsten Wert der Gruppe für die thermische Leitfähigkeit.

Die thermische Leitfähigkeit,  $k$ , ist gegeben in  $10^{-3}$  Joule  $\text{cm}^{-2} \text{sec}^{-1} (^\circ\text{C}, \text{cm}^{-1})^{-1}$ , deren Einheit =  $0,239 \times 10^{-3}$  g-cal  $\text{cm}^{-2} \text{sec}^{-1} (^\circ\text{C}, \text{cm}^{-1})^{-1}$ , =  $0,192 \times 10^{-3}$  BTU  $\text{ft}^{-2} \text{sec}^{-1} (^\circ\text{F}, \text{in.}^{-1})^{-1}$ . Umrechnungsfaktoren, Bd. I, p. 25.

Questa sezione comprende i diversi tipi di materiali isolanti che si trovano in commercio, i prodotti analoghi per costruzioni e materiali vari. Per il secondo gruppo di materiali, si consultino anche le sezioni della I. C. T., che trattano di queste classe di materiali.

Nelle tabelle seguenti, i diversi materiali sono disposti in gruppi approssimativamente secondo l'ordine della conduttività termica, crescente dalla più bassa del gruppo in su.

La conduttività termica,  $k$ , è data in  $10^{-3}$  joule  $\text{cm}^{-2} \text{sec}^{-1} (^\circ\text{C}, \text{cm}^{-1})^{-1}$ , di cui una unità =  $0,239 \times 10^{-3}$  g-cal  $\text{cm}^{-2} \text{sec}^{-1} (^\circ\text{C}, \text{cm}^{-1})^{-1}$ , =  $0,192 \times 10^{-3}$  BTU  $\text{ft}^{-2} \text{sec}^{-1} (^\circ\text{F}, \text{in.}^{-1})^{-1}$ . Vedi inoltre tomo I, p. 25, per altri fattori di conversione.

## THERMAL CONDUCTIVITY

Material	Bulk density, g/cm <sup>3</sup>	t°C	k	Lit.
Air.....	0.00129	0	0.23	(19, 22)
Silk.....			0.40	(30)
Scrap from spinning mill.....	0.101	0	0.442	(36)
		50	0.524	
		100	0.595	
Braided.....	0.147	0	0.455	(36)
		50	0.547	
		100	0.605	
Scrap from spinning mill.....	0.100	-200	0.232	(15)
		-150	0.314	
		-100	0.372	
		-50	0.437	
		0	0.495	
Fabric.....		50	0.559	(59)
		40	0.46	
"Calorox" (fluffy mineral matter).....	0.064	30	0.318	(52)
Slag wool (mineral wool).....	0.15	30	0.42	(14, 52)
	0.20	30	0.45	
	0.25	30	0.48	
	0.30	30	0.52	
With binder, waterprf. Rock cork..	0.25	30	0.50	(52)
Cork.....	v. infra p. 315.			
Ashes (soft wood).....		20	0.32	(32)
Rubber, hard sponge, rigid.....	0.087	25	0.34	(14)
	0.090	25	0.40	
	0.16	35	0.42	
Cellular (expanded after vulcanizing under very high gas pressure, cells unbroken).....	0.09	20	0.36	(14)
Sponge (vulcanizing rubber mixed with ammonium carbonate, cells broken).....	0.22	20	0.54	(14)
Ebonite.....	1.19	-190	1.38	(29, 50, 13, 20, 10, 11, 59)
		-78	1.57	
		0	1.60	
		30	1.76	
Soft, vulcanized.....	1.1	30	1.76	(52, 20)
Commercial, 40 % pure rubber.....		25	2.84	(59)
50 % pure rubber.....			2.21	(59)
67 % pure rubber.....			1.75	(59)
92 % pure rubber.....			1.63	(59)
100 % pure rubber (Plantation crepe)...			1.34	(59)
Kapok, loosely packed.....	0.015	20	0.35	(52, 4, 28)
Tightly packed.....			0.50	
Wool.....	0.09	0	0.372	(26)
		60	0.497	
Pure.....	0.09	30	0.364	(9)
Pure, very loose packing.....	0.04	30	0.423	
Slightly greasy.....	0.14	0	0.384	
		50	0.488	(36)
		100	0.582	
Blankets.....	0.08	75	0.77	(8)
	0.08	30	0.43	(42)
Cotton, tightly packed.....	0.08	-150	0.378	(36, 15)
		0	0.558	
		150	0.755	
Fabric.....		40	0.80	(59)
Cotton wool, tightly packed.....	0.08	30	0.42	(52, 23)
Glass wool.....	0.22	50	0.418	(41)
		100	0.500	
		200	0.651	
		300	0.813	
Wood fiber, shredded, soft, flexible ....	0.09	35	0.42	(55)
Rice paper.....		40	0.46	(59)
Blotting paper.....		20	0.63	(30)
Corrugated cardboard 5 layers per in..		20	0.63	(4)



THERMAL CONDUCTIVITY.—(Continued)

Material	Bulk density, g/cm <sup>3</sup>	t°C	k	Lit.
Pasteboard.....	0.69	30	0.71	(52)
Cardboard, various.....		50	1.7-3.4	(69)
Skeleton cardboard bricks (Ewing's)...		20	0.99	(14)
Felted flax fibers.....	0.18	30	0.47	(52)
Flax and paper lining for steel railway cars.....		30	0.45 to 0.65	(52)
Felt, asphalt-impregnated.....	0.88	30	1.01	(52)
Wood felt, flexible paper stock.....	0.33	30	0.52	(52)
Felted vegetable fibers.....	0.18	30	0.47	(52)
Wool felt.....	0.15	40	0.63	(50)
	0.33	30	0.52	(52)
Hair felt.....	0.27	30	0.36	(52)
Balsa wood, across grain.....	0.113	30	0.45	(52, 59)
Balsa wood, waterproofed.....	0.128	30	0.52	
Balsa wood, medium.....	0.143	30	0.553	(52)
Balsa wood, heavy.....	0.33	0	0.839	(52)
Pseudo balsa wood (⊥ grain).....	0.25		0.67	(59)
Pseudo balsa wood (   grain).....			1.21	(59)
Cottonseed hull fiber, loose pack.....	0.071	30	0.45	(52)
Eucalyptus bark fiber.....		0	0.45	(14)
Saragossa grass.....	0.15 0.22	30	0.45 0.49	(14)
Straw fibers, pressed.....	0.14	0	0.454 0.466	(25)
Elgrass.....	0.25	30	0.46	(52)
Ceiba wood, ⊥ grain, untreated.....	0.11	30	0.47	(52)
Curled cattle hair, loose, soft, flex.....	0.088	35	0.48	(55)
Sugar cane fiber (bagasse) board.....	0.25	35	0.54	(55)
Pressed wood pulp board.....	0.19	30	0.43	(52)
Waterproof lith board (slag wool, veg. fiber, waterprf. binder).....	0.20	30	0.55	(52)
Bulrush in cloth.....	0.14	30	0.49	(52)
<i>Kingia australis</i> (shredded fiber from outside layer of trunk).....	0.13	30	0.49	(14)
Solid from outside.....		30	0.76	
Solid from inside.....		30	1.06	
Horsehair, compressed.....	0.172	20	0.509 0.547	(26)
Diatomite.....	v., p. 315.			
Peat, dry.....	0.19	30	0.52	(36)
Peat boards.....	0.23	20	0.581	(18)
	0.37	20	0.873	
	0.73	20	1.16	
Peat blocks.....	0.84	20	1.74	(18)
Charcoal.....	0.18	20	0.55	(4, 14, 25, 36, 38)
Sawdust, various.....	0.20	30	0.60	(12, 52, 36, 8)
Shavings, various.....	0.14	30	0.60	(52)
Leather, chamois.....		85	0.63	(30)
Leather, cowhide.....		85	1.76	(30)
Leather, sole.....	1.0	30	1.59	(52)
Jongdala wood (⊥ grain).....		30	0.67	(14)
Jongdala wood (   grain).....		30	1.20	
Asbestos, cork, straw and diatomite steam-pipe covering, dry, loose	0.41	0	0.698 0.813 0.884 0.918 0.943	(36)
<i>Idem.</i> , molded with water to solid.....	0.69	150	1.16 220 1.40	(36)
Asbestos-diatomite, loose.....	0.550 0.609 0.625 0.668 0.609 0.609 0.609	50 50 50 50 100 200 300	0.941 0.918 0.860 1.06 0.918 0.930 0.953 0.965	(41)

THERMAL CONDUCTIVITY.—(Continued)

Material	Bulk density, g/cm <sup>3</sup>	t°C	k	Lit.
Asbestos, wool.....	0.40 0.50 0.60 0.70 0.40 0.40 0.40	0 0 0 0 -100 0 100	0.90 1.36 1.75 1.97 0.68 0.90 1.01	(15, 36, 4)
Asbestos, slate.....	1.8	50	2.2	(15)
Wood (asbestos and cement compressed).....	2.0	50	3.9	(52)
Pipe coverings of asbestos felt corrugated asbestos paper, etc.....	0.3 to 0.5	50	0.8 to 1.0	(52, 54, 31)
Paper, thin layers with organic binder	0.50	30	0.71	(52)
Paper.....		20	1.6	(30, 50)
Corrugated.....	0.14	30	0.66	(52)
Asbestos car lining.....	0.43	30	0.68	(52)
Asbestos-and-plaster blocks.....	0.29	30	0.815	(52)
	0.47	30	1.30	
Fire felt, flexible (asbestos sheet).....	0.42	30	0.86	(52)
Fire felt, rigid (asbestos sheet, cement coated).....	0.68	30	0.92	(52)
Asbestos-diatomite-cork (loose).....	0.33	50	0.813	(41)
	0.33	100	0.848	
	0.33	200	0.890	
Magnesia-asbestos (85 % MgO).....	0.3	30	0.75	(31, 52)
Cork linoleum.....	0.54	20	0.80	(15)
Linoleum (dry).....	1.18	0	1.75 1.86	(15)
Steel wool.....	0.152 0.101 0.076	55 55 55	0.803 0.875 0.904	(40)
Linen.....		20	0.86	(32)
Kiri wood (⊥ grain).....			0.88	(59)
Pumice gravel.....	0.3 0.6	20 0	0.92 1.75 1.86	(15) (18)
Cypress wood (⊥ grain).....	0.46	30	0.96	(52)
Coffee husks.....		30	0.98	(14)
Fuller's earth.....	0.53	30	1.01	(52)
Blast furnace slag.....	0.79	20	1.86	(18)
2 to 5 mm grain size No. 1.....	0.36	20	1.05	
3 cm grain size No. 2.....	0.36	20	1.51	
Nos. 1 and 2 mixed.....	0.30	20	1.28	(59)
Spruce (⊥ grain).....	0.41		1.1	
Spruce (   grain).....			2.2	(59)
Coal dust.....	0.73	30	1.11 90 1.25	(50)
White pine (⊥ grain).....	0.50	30	1.13	(52)
(   grain).....	0.45	60	1.07 2.57	(50)
Cedar (⊥ grain).....	0.48		1.13	(59)
Virginia pine (⊥ grain).....	0.55	30	1.38	(52, 59)
Pitch pine (⊥ grain).....		30	1.49	(14)
Cement paper, plain (14 layers each 0.38 mm).....	0.62	20	1.27 50 1.35	(50)
Cement paper, treated (12 layers, each 0.46 mm).....	1.02	20	1.56 50 1.65	
Cement wood (sawdust and Portland cement).....	0.71	0	1.28	(36)
		20	1.39	
	0.82	20	1.74	
Snow.....	0.50	0	1.3	(22)
	0.11	0	1.07	(24)
	0.45	0	0.49	
	0.24	0	1.67	(37)
	0.25	0	1.88	
	0.27	0	1.34	
Mahogany (⊥ grain).....	0.55	30	1.30 1.7	(52) (35)
(   grain).....	0.70	20	1.6 3.1	(59) (59)
Oak (⊥ grain).....	0.61	30	1.37	(52, 59)
	0.82	0	1.98	(38)
		15	2.10	

## THERMAL CONDUCTIVITY.—(Continued)

Material	Bulk density, g/cm <sup>3</sup>	t°C	k	Lit.
Oak (   grain).....	0.89	12	3.49	(38)
		20	3.61	
		50	4.31	
Soil, dry.....	2.04	20	1.38	(30)
wet.....		20	6.70	
normal, including stones 2 to 7 cm		0	5.00	(15)
		20	5.23	
		70	5.82	
Garden mold, dry.....			2.01	(35)
Teak (⊥ grain).....	0.64	0	1.63	(38)
		15	1.75	
		50	1.98	
(   grain).....	0.72	20	1.4	(59)
	0.60	12	3.72	(38)
		18	3.84	
		50	3.94	
Fir (⊥ grain).....	0.54	20	1.4	(38, 54, 59)
(   grain).....	0.55	20	3.5	(38)
Walnut (⊥ grain).....	0.65	20	1.4	(59)
(   grain).....			3.3	
Baobab wood (   grain).....		30	1.41	(14)
Fuller board, treated				(50)
11 layers each 0.51 mm.....	1.39	20	1.61	
		50	1.75	
16 layers each 0.76 mm.....	1.15	20	6.1*	
		50	6.9*	
4 layers each 1.42 mm.....	1.09	20	1.49	
		60	1.66	
2 layers each 3.1 mm.....	0.95	20	1.42	
		50	1.46	
Fuller board soaked in transformer oil				
3 layers each 3.18 mm.....	1.01	20	2.12	
		50	2.27	
		50	5.15*	
Fuller board, untreated				
15 layers each 0.38 mm.....	1.38	20	2.68	
		50	2.68	
7 layers each 7.6 mm.....	1.26	20	2.55	
		50	2.63	
16 layers each 7.6 mm.....	1.28	20	6.28*	
		50	6.62*	
21 layers each 0.25 mm.....	1.39	20	2.60	
		50	2.89	
4 layers each 1.42 mm.....	1.15	20	1.95	
		50	2.15	
9 layers each 1.42 mm.....	1.15	20	6.37*	
		50	6.90*	
3 layers each 3.18 mm.....	1.01	20	1.45	
		50	1.62	
Facing cement (Mg oxychloride).....		0	1.46	(14)
Boxwood.....	0.90	20	1.51	(3)
		100	1.72	
Coke dust.....	1.00	20	1.51	(18)
Concrete, pumice gravel and cement. .	0.60	20	1.51	(15)
		30	1.63	
Pumice pebbles 9, fine sand 2, } Portland cement 1	1.17	85	2.3	(8)
1: 12, air-dried 2 weeks.....	2.05	0	7.66	(38)
		20	8.15	
		30	8.36	
Granulated cork 3, fine sand 2, } Portland cement 1	1.27	85	2.58	(8)
Slag 9, fine sand 2, Portland cement 1	1.52	85	2.96	(8)
Lime mortar, "Beffes No. 3".....	1.75	90	3.51	(8)
Cement mortar, Portland No. 1.....	1.72	90	3.36	(8)
Portland No. 2.....	1.89	90	5.35	(8)
Concrete, blast furnace slag 9 pts vol., cement 1 pt. vol.....	0.55	50	2.21	(36)
Concrete.....	1.6	0	8.36	(26)
Concrete plus moisture 10 % by volume	2.3	0	12.1	
Cement mortar 10.5 mm thick, includ- ing 4 mm reinforcing metal.....	2.12	90	5.77	(8)
12.0 mm thick, including 3 mm reinforcing metal.....	1.97	90	5.97	(8)
Concrete, gravel 9, fine sand 2, cement 1.....	1.99	90	6.40	(8)

\* Longitudinally.

## THERMAL CONDUCTIVITY.—(Continued)

Material	Bulk density, g/cm <sup>3</sup>	t°C	k	Lit.
Concrete, gravel 9, fine sand 2, cement 1, air-dried six months.....	2.18	20	7.65	(15)
Portland cement.....	2.0	60	3.0	(36, 30)
Ash (⊥ grain).....	0.74	20	1.7	(59)
(   grain).....			3.1	(59)
Bricks, very porous, dry.....	0.71	20	1.74	(18)
	0.81	20	1.98	
Bricks, very porous, moisture 1.2 % volume.....	0.74	20	1.69	(7)
Moisture 5.8 % volume.....	0.79	20	2.44	
Moisture 21.5 % volume.....	0.94	20	3.96	
Bricks, hand-made, dry.....	1.54	0	3.83	(38)
Bricks, machine-made, dry.....	1.67	0	5.12	(38)
		40	5.35	
		80	5.46	
	1.62	50	4.81	(25)
Bricks, machine-made				(25)
Moisture 0.8 % volume.....		50	4.99	
Moisture 1.2 % volume.....		50	9.56	
Old brick masonry.....	1.85	0	3.82	(15)
		20	4.07	
		47	4.42	
Maple (⊥ grain).....	0.72	30	1.70	(52, 50)
(   grain).....	0.72	30	4.35	(50)
Fish paper				(50)
21 layers each 0.25 mm.....	1.06	20	1.72	
		50	1.81	
75 layers each 0.25 mm.....	1.06	20	4.80*	
		50	5.08*	
10 layers each 0.58 mm.....	1.03	20	2.01	
		50	2.16	
6 layers each 1.4 mm.....	1.01	20	2.37	
Paraffined fish paper				
30 layers each 0.18 mm.....	1.06	20	1.92	
		50	2.02	
15 layers each 0.38 mm.....	1.13	20	2.17	(50)
		50	2.19	
8 layers each 0.97 mm.....	1.15	20	2.07	
Powdered graphite				(50)
100 mesh.....	0.48	40	1.83	
40 mesh.....	0.42	40	3.85	
20 mesh on 40 mesh.....	0.70	40	11.9	
Cement paper and mica				(50)
No. 226, 5.7 mm thick.....		20	1.85	
		50	1.93	
No. 227, 5.05 mm thick.....		20	1.95	
		50	2.08	
No. 247, 5.7 mm thick.....		20	2.10	
		50	2.18	
No. 227, 13 mm thick.....		20	9.32*	
		50	9.88*	
Fish paper and mica.....		60	2.0	(50)
Celluloid, white.....	1.4	30	2.10	(52)
Fiber, vulcanized.....		50	2.1-3.3	(59)
Fiber, white.....	1.2	20	2.76	(50)
		50	2.91	(50)
Micanite.....		30	2.1-4.2	(59)
Varnished cambric, tacky				(50)
30 layers each 0.23 mm.....	1.17	20	2.17	
		50	2.28	
75 layers each 0.23 mm.....	1.17	20	4.30*	
		50	4.38*	
Varnished cambric, dry.....	1.24	20	2.16	(50)
30 layers each 0.23 mm.....		50	2.23	
Kraft paper and mica, No. 312, 13.2 mm thick.....		20	11.2*	(50)
		50	11.8*	
Idem., 5.6 mm thick.....		50	2.28	
Paraffin wax.....	0.89	30	2.30	(52)
Micarta folium, No. 249, 5.9 mm thick. 14.5 mm thick.....		50	2.31	(50)
		50	11.3*	
Cellulose, compressed.....	1.42	15	2.44	(4)

\* Longitudinally.



## THERMAL CONDUCTIVITY.—(Continued)

Material	Bulk density, g/cm <sup>3</sup>	t°C	k	Lit.
Presspan.....		54	2.49	(49)
Black bias cloth, 22 layers each 0.23 mm.....	1.26	50	2.51	(50)
80 layers each 0.23 mm.....	1.26	20	3.82*	
		50	4.26*	
Lignum-vitae.....	1.16	20	2.52	(3)
		100	3.02	
Mica tape, 30 layers each 0.15 mm....	1.06	50	2.63	(50)
30 layers each 0.20 mm.....	1.12	50	2.63	
120 layers each 0.15 mm.....	1.06	50	14.5*	
Plaster of paris, powder.....		20	10.9	(30)
Plaster of paris, cast.....		20	3.0	
Fine river sand, dried.....	1.52	0	3.02	(15)
		20	3.26	
		160	3.84	
Fine river sand with normal moisture content (ca.6.9 % by weight).....	1.64	20	11.3	(15)
		50	11.5	
Gypsum plaster.....	0.74	30	3.35	(52)
Plaster.....	1.69	20	7.9	(15)
Mica.....		41	3.6	(49)
Mica, various.....		50	4.2-5.9	(59)
Gravel.....	1.85	20	3.7	(15)
Bitumen.....		30	4.2 to 6.3	(14)
Flooring composition.....		30	8.5	(14)
Greenhart.....	1.08	20	4.69	(3)
		100	4.61	
Water.....	1.0	20	5.9	(22)
Glass, lead.....		15	6.0	(33)
Glass, soda.....	2.59	20	7.2	(3, 33, 50)
		100	7.6	
Limestone, Villers-Adam, soft.....	1.81	90	6.01	(8)
Lerouville, hard.....	2.55	90	12.9	(8)
Fine-grained, dry.....	1.66	0	6.29	(38)
		25	6.86	
		40	7.21	
Coarse-grained, dry.....	1.99	0	8.38	(38)
		25	9.30	
		40	9.90	
Caen stone.....			18.0	(20)
Limestone.....		0	19 to 24	(39)
		100	16 to 21	
		350	13 to 15	
Asphalt composition.....	2.12	0	6.05	(38)
		10	6.52	
		20	6.98	
		30	7.44	
Alumina (compressed powder).....	1.84	47	6.77	(27)
Chalk.....			9.2	(20)
Porcelain.....		90	10.4	(30)
Slate, ⊥ cleavage.....		95	15.0	(30)
			13.2 to 15.1	(20)
Slate,    cleavage.....			23.0 to 27.2	
Sandstone, grey, natural, freshly cut..	2.26	10	15.5	(38)
		20	16.7	
		40	18.4	
Sandstone, air-dried six months.....	2.25	0	12.2	(38)
		20	12.9	
		30	13.2	
Basalt.....		20	20	(53, 46, 17, 39)
Ice.....	0.92	0	22	(22, 34, 43)
Granite.....	2.8		22	(20)

Hollow Tile Ceiling (4).  $k$  at 10°C.—Sample A: Top tile 1, air 2.5, tile 1, air 11, tile 1, air 2.5, tile 1 cm,  $k = 6.86$ . Sample B: Top tile 0.85, air 0.8, tile 0.85, air 13, tile 0.85, air 0.8, tile 0.85, concrete 3 cm,  $k = 6.76$ . Sample C: Same as B but with the 13 cm air space filled with concrete,  $k = 11.9$ . Heat flow up.

## THERMAL CONDUCTIVITY OF DIATOMITE

$d \backslash t$	0°C	100°	200°	300°	400°	Remarks
0.20	0.52	0.62	0.73	0.83	0.94	Average values. The use of binding materials will increase the conductivity by amounts varying up to 100% (5, 14, 18, 36, 38, 44, 52)
0.30	0.61	0.74	0.86	0.98	1.11	
0.40	0.73	0.88	1.03	1.18	1.34	
0.50	0.86	1.03	1.21	1.39	1.57	

## THERMAL CONDUCTIVITY OF CORK

$d \backslash t$	0°C	20°	40°	60°	80°	100°	Remarks
0.05	0.32	0.34	0.36	0.37	0.39	0.41	Average values. Use of binding materials gives increases up to 30 % (4, 8, 14, 15, 26, 36, 38, 44, 52, 57, 58)
0.10	0.37	0.39	0.41	0.43	0.45	0.47	
0.20	0.46	0.49	0.52	0.54	0.57	0.60	
0.30	0.56	0.60	0.63	0.66	0.69	0.73	
0.35	0.61	0.65	0.68	0.72	0.75	0.79	

## THERMAL CONDUCTIVITY OF POWDERS UNDER REDUCED AIR PRESSURES

For granular powders, Smoluchowski gives the following formula connecting the thermal conductivity  $k$  with the pressure  $p$  of the gas in the interstices:

$$k = A \log (1 + ep)$$

where, for a given gas  $A$  is a constant depending on the arrangement of the grains and  $e$  on the material of which they are composed. For spongy powders this law does not hold. In the following table the conductivity of various powders (having the indicated average grain diameters in mm) is given in hectoerg (=10<sup>-5</sup> joule) per cm<sup>2</sup> per sec per (deg. C per cm). Smoluchowski, *Acad. Sci. Crac. Bull.* 5b: 129; 10 and 8a: 548; 11.

Pressure mm Hg	Quartz 0.26 mm	Emery 0.11 mm	Quartz 0.09 mm	Lycopodium 0.03 mm	Zinc 0.028 mm	Iron 0.025 mm	Rice 0.003 mm	Diatomite	Lamp-black
0.05	1.4		0.6						
0.10	2.8		1.1					1.3	
0.20	5.6	2.0	2.1	1.0	1.1	0.9	0.6	2.1	1.0
0.50	11.7	5.0	4.8	2.2	2.4	1.9	1.3	3.9	2.0
1.0	20.1	8.8	8.8	4.1	4.4	3.4	2.3	5.9	3.0
2.0	33.5	15.1	15.1	6.9	7.5	5.9	3.7	8.8	4.2
5.0	61	28.5	29.7	13.1	15.1	12.2	7.1	13.4	6.6
10	88	43.9	48.1	20.5	25.1	20.5	10.9	17.6	8.4
20		66	71	28.9	40.1	33.5	16.3	21.8	10.5
50		88		38.9	67	59	24.7	26.8	13.8
100		105		43.9	88	77	31.8	30.1	16.3
200		113		46.0	109	100	38.5	33.1	18.8
400		121		48.1	126	121	43.9	34.8	21.3
700		128		50	136	132	48.1	35.6	23.4
Solid					111000	60100			

## THERMAL DIFFUSIVITY

Thermal diffusivity,  $\Delta t = k/dc$ , where  $k$  = thermal conductivity,  $d$  = bulk density,  $c$  = specific heat.  $\Delta t = 10^{-3} \times A$  cm<sup>2</sup> sec<sup>-1</sup>

Material	A	Lit.
Gutta-Percha, 43°.....	0.486	(45)
Ebonite.....	0.928	(47)
Coal.....	1.13	(17, 34)
Rubber, 26°.....	1.42	(45)
Water, 20°.....	1.43	(22)
Snow ( $d = 0.19$ ), 0°.....	2.50	(1)
( $d = 0.33$ ), 0°.....	4.60	(1)
(densely packed), 0°.....	4.1	(21)
Gypsum.....	3.0	(17)
Soil, very dry.....	3.1	(22)
Garden sand.....	3.6	(6)
Sandy clay.....	5.1	(6)
Coarse sand.....	7.6	(6)
Garden sand.....	8.7	(6)

## THERMAL DIFFUSIVITY.—(Continued)

Material	A	Lit.
Frozen mold.....	9.2	(56)
Gravel.....	12.5	(56)
Sandy loam.....	13.6	(6)
Porphyritic trachyte.....	5.9	(2)
Trap rock.....	7.86	(51)
Sandstone.....	10.7	(51)
Marble.....	11.1	(17, 46)
Ice, 0°.....	11.4	(34)
Basalt.....	11.5	(46)
Granite.....	13.1	(34, 46)

## ADSORBED MOISTURE IN EQUILIBRIUM WITH AIR OF VARIOUS HUMIDITIES (60)

Rel. humidity, %	Moisture content (per cent of dry weight)				
	15	30	50	70	90
Absorbent cotton (cottonwool)....	8.9	10.1	20.6	22.2	25.8
Cotton cloth.....	2.99	4.56	6.7	9.6	13.5
Raw silk.....	5.0	7.1	9.0	13.3	19.0
Paper pulp (pine).....	4.55	6.3	7.9	9.5	12.0
Kraft paper.....	2.50	3.85	5.4	7.0	9.2
Sole leather.....	7.0	11.1	16.0	20.6	29.2
Feathers.....	5.0	6.4	8.1	10.4	12.7
Rubber (solid tire).....	0.17	0.28	0.60	0.74	0.99
Fuller's earth.....	4.54		7.5		15.6
Asbestos fiber.....	0.22	0.26	0.40	0.62	0.84
Diatomite.....	0.50	0.88	1.40	2.00	3.19
Kaolin.....	0.30	0.60	0.92	1.06	1.27
Glass wool.....	0.09	0.09	0.17	0.23	0.40
Lampblack.....	2.48	3.42	3.85	4.31	6.0

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(For a key to the periodicals see end of volume)

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## THERMAL INSULATING MATERIALS FOR HIGH TEMPERATURE

GORDON B. WILKES

	Bulk density, g/cm <sup>3</sup>	Max. safe tem- perature for con- tinuous use, °C	Mean coefficient of thermal con- ductivity* 600 to 25°C
<i>Insulating blocks composed chiefly of</i>			
1. Diatomaceous earth and asbestos.....	0.32-0.40	700- 900	0.00072-0.00096
2. Rock and slag wool mixtures.....	0.26-0.40	700- 900	0.00090-0.00120
<i>Insulating bricks</i>			
1. Diatomaceous earth (natural).....	0.48	850-1000	0.00066-0.00108
2. Clay, diatomaceous earth and cork (fired).....	0.43	850-1000	0.00096-0.00120
3. Diatomaceous earth and clay (fired).....	0.64-0.96	1100-1300	0.00150-0.00360

\* Joule, cm<sup>-2</sup> sec<sup>-1</sup> (°C, cm<sup>-1</sup>).

Values taken from U. S. Bur. Stand., trade catalogs of The Celite Products Co., Armstrong Cork and Insulation Co., and mainly from determinations in Heat Measurement Laboratory, Mass. Inst. Tech.



## RAW MATERIALS OF THE PAINT AND VARNISH INDUSTRIES

AVERAGE BULKING VALUES AND SPECIFIC GRAVITIES OF THE MORE COMMON  
DRY PIGMENTS USED IN THE PAINT INDUSTRY

HENRY A. GARDNER AND H. C. PARKS

	Specific gravity	Wt. per solid gal., lb.	1 lb. bulks, gal.		Specific gravity	Wt. per solid gal., lb.	1 lb. bulks, gal.
Basic carbonate white lead.....	6.81	56.73	0.01763	Chromium oxide.....	4.95	41.23	0.02425
Basic sulfate white lead.....	6.41	53.40	0.01873	Litharge.....	9.40	78.30	0.01277
Zinc oxide.....	5.66	47.15	0.02121	Orange mineral.....	8.80	73.30	0.01364
Zinc oxide, leaded (contains 35 % basic lead sulfate).....	5.95	49.56	0.02018	Red lead.....	8.80	73.30	0.01364
Lithopone (ca. 28 % ZnS, 72 % BaSO <sub>4</sub> ).....	4.30	35.82	0.02792	Pure paranitraniline toner.....	1.50	12.50	0.08000
Titanox (25 % TiO <sub>2</sub> , 75 % BaSO <sub>4</sub> ).....	4.30	35.82	0.02792	Para red 10 % (on lime and barium base).....	2.65	22.07	0.04531
Talc (contains ca. 5 % CaCO <sub>3</sub> ).....	2.85	23.74	0.04212	Pure toluidine red toner.....	1.49	12.41	0.08058
Barytes.....	4.45	37.07	0.02698	Chrome green, C. P. .... {	3.90*		
China clay.....	2.62	21.82	0.04583		5.08*		
Silica.....	2.65	22.07	0.04531	American blue (iron cyanide blue)...	1.85	15.41	0.06489
Whiting (CaCO <sub>3</sub> ).....	2.71	22.57	0.04431	Ultramarine blue.....	2.35	19.58	0.05107
Venetian red (20 % Fe <sub>2</sub> O <sub>3</sub> )* .....	3.05	25.41	0.03935	Chrome yellow, C. P* .....	6.00*		
Red oxide (40 % Fe <sub>2</sub> O <sub>3</sub> ).....	3.45	28.74	0.03479	Lampblack.....	1.78	14.83	0.05743
Red oxide (95 % Fe <sub>2</sub> O <sub>3</sub> ).....	4.95	41.23	0.02425	Carbon black.....	1.81	15.08	0.06631
Indian red (90 % Fe <sub>2</sub> O <sub>3</sub> ).....	4.92	40.98	0.02440	Drop black.....	2.64	21.99	0.04548
Ferric oxide (98 % Fe <sub>2</sub> O <sub>3</sub> ).....	5.15	42.90	0.02331	Graphite.....	2.36	19.66	0.05086
Tuscan red.....	3.95	32.90	0.03040	Mineral black filler (clay base with from 15 to 30 % carbon).....	2.71	22.57	0.04431
Ochre.....	2.80	23.32	0.04288	Zinc dust.....	7.06	58.81	0.01700
Sienna, raw.....	3.27	27.24	0.03671	Aluminum dust.....	2.64	21.99	0.04548
Sienna, burnt.....	3.95	32.90	0.03040	Lead dust.....	11.09	92.38	0.01082
Umber, raw.....	2.68	22.32	0.04480	* These will vary widely according to composition required for shade or tone and character of base. Red and brown oxides of variable composition. Matter other than iron oxide may be clay, silica, etc.			
Umber, burnt.....	3.80	31.65	0.03160				
Brown oxide (50 % Fe <sub>2</sub> O <sub>3</sub> ).....	3.35	27.91	0.03583				
Mineral brown (45 % Fe <sub>2</sub> O <sub>3</sub> ).....	3.34	27.82	0.03595				

## AVERAGE CONSTANTS OF OILS USED IN PAINT AND VARNISH INDUSTRY

HENRY A. GARDNER AND L. L. STEELE

Oil	Species	Specific gravity 15.5°C 15.5°C	Iodine (Hanus) No.	Saponifi- cation No.	Acid No.	Refractive index 25°C
Vegetable and seed oils						
Chia.....	<i>Salvia hispanica</i>	0.934	196	192	0.6	1.486
Corn.....	<i>Zea mays</i>	0.921	125	190	4.0	1.480
Cottonseed.....	<i>Gossypium herbaceum</i>	0.924	112	194	0.9	1.472
Hempseed.....	<i>Cannabis sativa</i>	0.927	149	191	4.0	1.482
Kapok seed.....	<i>Eriodendron anfractuosum</i>	0.924	119	196		
Linsced (boiled).....	<i>Linum usitatissimum</i>	0.941	172	187	2.7	1.490
Linseed (heavy bodied).....	<i>Linum usitatissimum</i>	0.968	133	189	2.8	1.497
Linseed (lithographic).....	<i>Linum usitatissimum</i>	0.970	102	199	2.7	1.498
Linseed (raw).....	<i>Linum usitatissimum</i>	0.934	186	191	2.0	1.480
Oticia.....	<i>Conepia grandifolia</i>	0.969	180	189	8.0	
Palo maria.....	<i>Calophyllum inophyllum</i>	0.934	97	193	46.0	1.474
Perilla.....	<i>Perilla ocimoides</i>	0.934	200	188	2.0	1.487
Poppyseed.....	<i>Papaver somniferum</i>	0.926	134	192		
Raisinseed (grape seed).....	<i>Vites, spp.</i>	0.926	133	193	4.5	1.471
Rosin oil.....	<i>Pinus palustris</i>	0.964	69	36	32	
Rubberseed.....	<i>Hevea brasiliensis</i>	0.924	137	193	57	
Sesame.....	<i>Sesamum orientale &amp; indicum</i>	0.924	110	190	1.5	
Soya bean.....	<i>Soja hispida</i>	0.924	129	189	2.3	1.481
Sunflower.....	<i>Helianthus annuus</i>	0.924	125	189	7.5	1.480

Oil	Species	Specific gravity 15.5°C 15.5°C	Iodine (Hanus) No.	Saponifi- cation No.	Acid No.	Refractive index 25°C
Nut oils						
Lumbang (candlenut).....	<i>Aleurites moluccana</i>	0.927	152	192	1.0	1.477
Lumbang (soft).....	<i>Aleurites trisperma</i>	0.938	164	194	4.4	1.493
Peanut.....	<i>Arachis hypogaea</i>		102	193	2.2	1.479
Tung (American).....	<i>Aleurites fordii</i>	0.941	166	195	0.2	1.517
Tung (Chinese).....	<i>Aleurites fordii</i>	0.944	165	192	4.8	1.517
Walnut.....	<i>Juglans regia</i>	0.926	143	193		1.477
Wood (Japanese).....	<i>Aleurites cordata</i>	0.934	154	193	0.9	1.508
Marine animal oils						
Channel catfish.....		0.923	123	192	11	1.474
Fur seal.....	<i>Phoca vitulina</i> , etc.	0.925	132	182	9	1.477
Grayfish.....		0.916	135	180	2	1.470
Menhaden.....	<i>Alosa menhaden</i> ( <i>Brevoortia tyrannis</i> )	0.932	158	187	4	1.485
Salmon.....	<i>Salmo salar</i>	0.927	159	183	10	1.479
Sardine.....	<i>Clupea sardinus</i>	0.919	135	177	10	1.480
Shark.....		0.910	133	160	5	1.482
Shark liver.....	<i>Borealis scymnus</i>	0.922	136	62	1.5	1.471
Skate liver.....	<i>Squatina vulgaris</i>	0.932	152	180	2	1.471
Tuna fish.....		0.933	184	190	0.5	
Whale.....	<i>Balæna</i>	0.924	148		9	1.482
Yellow tail fish.....	<i>Seriola dorsalis</i>	0.932	180	190	0.6	

## TOXICOLOGY OF GASES AND VAPORS

R. R. SAYERS

### EFFECTIVE CONCENTRATIONS AND PROPERTIES

In the following paragraphs the numbers in bold face have the following significance:

1. Boiling point.
2. Percentage fatal in 30 minutes or less.
3. Percentage causing dangerous illness in 0.5 to 1 hour.
4. Percentage that can be borne without severe effects for 0.5 to 1 hour.
5. Maximum safe concentration.
6. Properties (1).
7. Portal of entry (1).
8. Symptoms (1).
9. Occupations (1).

**Acrolein**,  $\text{CH}_2\text{:CHCHO}$ .—1. 52°. 2. 0.001 (2). 5. 0.00033 (2). 6. Colorless, pungent fluid, of fiery taste. 7. As vapor, through organs of respiration and mucous membranes. 8. Itching in the throat; irritation of eyes, exciting lachrymation; conjunctivitis, irritation of the air passages, bronchial catarrh. 9. Manufacture of lard, linoleum, stearic acid; bone and fat rendering, galvanizing, tallow refining, tinsmithing, varnish boiling.

**Ammonia**,  $\text{NH}_3$ .—1. -35.5°. 3. 0.25-0.45 (3). 4. 0.03 (3). 6. Colorless gas of sharply penetrating odor. 7. As gas, through organs of respiration. Seldom pure, mostly in combination with other gases. Immediate effects on the conjunctiva and the cornea. 8. Acute inflammation of the respiratory organs, cough, edema of the lungs, chronic bronchial catarrh, redness of the eyes, increased secretion of saliva, retention of urine. 9. Manufacture of acetylene, ammonium salts, artificial ice, artificial silk, bone-black, dyes, shellac, soda, varnish; work around coke-ovens, refrigerating plants, sewers; bronzing, dyeing, galvanizing, gas purifying, mercerizing, shoe finishing, sugar refining, tinsmithing; work with glue, illuminating gas.

**Aniline**,  $\text{C}_6\text{H}_5\text{NH}_2$ .—1. 184.4°. 4. 0.00004-0.00006 (3). 6. Colorless oil acquiring tint on exposure to air and light. 7. Absorption through skin, directly or by saturation of clothing; absorption through respiratory organs as volatile particles and impalpable dust; through digestive organs. 8. Pallor of skin, vertigo, unsteady gait, loss of appetite, increased frequency of respiration, anemia, slowing of the pulse, eczematous eruptions, bloody urine, spasmodic muscular pains, cyanosis. 9. Manufacture of aniline, artificial leather, calico, explosives, coal-tar products, dyes, paint, colored pencils; vulcanizing, tanning, printing, typesetting, photography, painting, lithography; work with feathers; compounding, mixing, reclaiming rubber, and work in press rooms.

**Arsine**,  $\text{AsH}_3$ .—1. -54.8°. 2. 0.05 (2). 5. 0.001 (2). 6. Colorless, extremely offensive gas, with the odor of garlic. 7. As gas, through respiratory organs, generally mixed with hydrogen. 8. General malaise, difficult breathing, fainting fits, gastric disturbances, jaundice, bluish discoloration of the mucous membrane, pain in the region of spleen and kidney, darkened urine, fetor of the mouth resembling garlic. 9. Manufacture of dry batteries, dimethyl sulfate, dyes, fertilizer, nitroglycerin, shoddy, zinc chloride; acid dipping, filling toy balloons, bronzing, enameling, galvanizing, lead and lime burning, pickling, metal refining, tinsmithing; work with aniline, sulfuric acid, submarine storage batteries; ferro-silicon work.

**Benzene**,  $\text{C}_6\text{H}_6$ .—1. 80.2°. 4. 0.001-0.0015 (3). 5. 0.0005 (3). 6. Unstable, extremely volatile, colorless fluid, burning with a bright sooty flame. A coal tar product. 7. As vapor, through the respiratory organs; re-absorption through the skin. 8. Headache, vertigo, anemia, muscular tremor, scarlet lips, spots of extravasated blood in the skin, irritant cough, fatty degeneration of liver, kidneys and heart. 9. Manufacture of aniline, artificial leather, dry batteries, carbolic acid, colors, dyes, explosives, fertilizer, lacquer, paint, rubber tires, shellac, shoes,



- smokeless powder, varnish; vulcanizing, coal-tar still cleaning, photography, photoengraving, painting, lithography, gilding, electroplating, dry cleaning, leather and fertilizer degreasing, pottery decorating, case scrubbing, bronzing; compounding, drying, mixing, washing, reclaiming, treading rubber; mixing rubber cement, cementing rubber shoes; work with benzol stills, coke ovens, coal tar, feathers, illuminating gas, glue, mordants.
- Bromine, Br<sub>2</sub>.—**1. 58.6°. 2. 0.1 (3). 3. 0.004–0.006 (3). 4. 0.0004 (3). 5. 0.0001 (3). 6. Fuming liquid with an extremely disagreeable odor. 7. As gas, through the respiratory organs. 8. Pallid countenance, emaciation, decayed teeth, bronchial irritation and asthma, gastric disturbances, irritation of the skin. 9. Manufacture of dyes; chemical and pharmaceutical industries.
- Carbon Disulfide, CS<sub>2</sub>.—**1. 46.2°. 3. 0.001 (3). 4. 0.0002–0.0003 (3). 5. 0.0001 (3). 6. When pure, a limpid, highly refractive, volatile fluid, having an odor like chloroform; imperfectly refined, it is pale yellow, with an offensive odor. 7. As vapor, through respiration; as fluid, through the skin. 8. Headache, pain in the extremities, trembling, deafness, reduction of the reflexes, accelerated heart action, nausea, digestive trouble, emaciation, disturbance of sense of vision, excitement and violent temper followed by depression, hyperstimulation of the sexual instinct, later its abnormal decline, chronic dementia. 9. Manufacture of ammonium salt, artificial silk, carbon disulfide, celluloid, insecticide, matches, paint, putty, smokeless powder; asphalt testing, cementing rubber shoes, rubber cement mixing, dry cleaning, enamelling, oil extracting, tallow refining, sulfur extracting, vulcanizing, rubber drying and reclaiming, work with paraffin and glue.
- Carbon Dioxide, CO<sub>2</sub>.—**1. –78.2°. 2. 30.0 (3). 3. 6.0–8.0 (3). 4. 4.0–6.0 (3). 5. 2.0–3.0 (3). 6. Specifically dense, odorless, colorless gas, collecting near the ground or floor. 7. As gas, by inhalation. 8. Anemia, cyanosis, headache, drowsiness, vertigo, tinnitus, and general nervousness. 9. Manufacture of alkali salts, carbon dioxide, fertilizer, pottery, soda, starch, wine, white lead, yeast; blacksmithing, brass founding, brewing, brick, charcoal and lime burning, lime kiln charging, mining, sugar refining; work in boiler rooms, caissons, drying rooms, silos; work around furnaces, sewers.
- Carbon Monoxide, CO.—**1. –190°. 2. 0.5–1.0 (7). 3. 0.2–0.3 (3). 4. 0.05–0.10 (3). 5. 0.04 (7). 6. Colorless, tasteless gas, odorless in diffused state, burning with a blue flame in air. 7. As gas, through the respiratory organs. 8. Stage 1 (7): Tightness across forehead, dilatation of cutaneous vessels, headache (frontal and basal), throbbing in temples, weariness, weakness, dizziness, nausea and vomiting, loss of strength and muscular control, increased pulse and respiration rates, collapse. Stage 2: Increased pulse and respiration, fall of blood pressure, loss of muscular control, especially sphincters, loss of reflexes, coma usually with intermittent convulsions, Cheyne-Stokes' respiration, slowing of pulse, respiration slow and shallow, cessation of respiration, death. 9. Manufacture of acetylene, carbide, celluloid, cores (founding), felt hats, incandescent lamp filaments; baking, blacksmithing, brass founding, cable splicing, calico printing, charcoal burning, charging (zinc smelting), chimney sweeping, copper smelting, enamelling, incandescent lamp finishing; work with bisque kilns, coke ovens, coal tar; work in drying and boiler rooms.
- Carbon Tetrachloride, CCl<sub>4</sub>.—**1. 76.74°. 2. 0.03–0.04 (3). 3. 0.015–0.02 (3). 4. 0.0025–0.004 (3). 5. 0.001 (3). 6. Colorless liquid with pleasant odor, having a narcotic action somewhat similar to chloroform (11). 7. As vapor, through the respiratory organs. 8. Nausea, vomiting, abdominal pain, stupor deepening into coma, absence of reflexes, clonic convulsions, weak pulse, increased temperature and death (11). 9. Used in industry as a rubber solvent, an ingredient of certain types of paint, a fire extinguisher, and a shampooing agent.
- Chlorine, Cl<sub>2</sub>.—**1. –33.6°. 2. 0.10 (3). 3. 0.004–0.006 (3). 4. 0.0004 (3). 5. 0.0001 (3). 6. Yellowish-green, suffocating gas of penetrating odor, whose water solution is a greenish-yellow. 7. As gas, through the respiratory organs. 8. Pallid countenance, emaciation, decayed teeth, bronchial irritation and asthma, gastric disturbances, irritation of the skin, chloracne. 9. Manufacture of alkali salts, brooms, chloride of lime, chlorine, disinfectants, dyes, phosgene, sulfur and zinc chloride; pulp beating, bleaching, calico printing, laundry work, photography.
- Chloroform, CHCl<sub>3</sub>.—**1. 61.2°. 2. 0.03–0.04 (3). 3. 0.007 (3). 4. 0.0025–0.003 (3). 5. 0.001 (3). 6. Heavy colorless liquid, with characteristic odor and sweet taste; used as an anesthetic (11). 7. As vapor, through the respiratory organs. 8. In anesthesia the untoward symptoms are shallow or irregular respiration, sudden cessation of respiration, pulse either very slow or very rapid, dilatation of the pupils, cyanosis, asphyxia leading to dilatation of the heart, vagus stimulation, and finally failure of heart due to asphyxial condition. In delayed poisoning there is great prostration, delirium, coma, death (11). 9. Chloroform manufacture, but the principal hazard is in its use as an anesthetic.
- Chloropicrin, CCl<sub>3</sub>NO<sub>2</sub>.—**1. 112°. 2. 0.05 (2). 3. 0.002 (2). 4. 0.0001 (2). 6. Colorless oil, insoluble in water. Sufficiently volatile to keep the strata of air above it thoroughly poisonous, and persistent enough to be dangerous after 5 or 6 hours. 7. As gas, through the respiratory organs. 8. Lachrymatory and respiratory irritant, with specific action on the vomiting center. Causes coughing, nausea, vomiting, and in large quantities unconsciousness. Secondary effects are bronchitis, shortness of breath. 9. Warfare.
- Dichlorodiethyl Sulfide, (CH<sub>2</sub>ClCH<sub>2</sub>)<sub>2</sub>S.—**1. 215–217°. 5. 0.002 (2). 6. Oily fluid with sharp odor. Its peculiar property of blistering the skin, combined with its high persistency, makes it the most valuable war gas known. 7. As vapor, through the respiratory passages, and through the skin. 8. Conjunctivitis and superficial necrosis of the cornea; hyperemia, edema and, later, necrosis of the skin, leading to skin lesion of great chronicity; congestion and necrosis of the epithelial lining of the trachea and bronchi. Systemic effects due to the absorption of the substance into the blood stream and its distribution to the various tissues of the body (4). 9. Warfare.
- Hydrogen Chloride, HCl.—**1. –82.9°. 2. 0.5 (2). 3. 0.15–0.2 (3). 4. 0.005–0.01 (3). 5. 0.005 (2). 6. Pure HCl is a colorless gas that fumes when open to the air, forming a dense, acid, white mist. The crude commercial acid is, for the most part, impure, containing arsenic among other mixtures. 7. Action on skin and nasal mucous membrane; seldom as vapor affecting the respiratory organs. 8. Irritation of mucous membranes, conjunctivitis, coryza; pharyngeal, laryngeal, and bronchial catarrh; dental caries. 9. Manufacture of alkali salts, ammonium salts, aniline, dry batteries, camphor, carbolic acid, dyes; dipping, mixing, recovering, transporting acid; cartridge dipping, shoddy carbonizing, calico printing, acid finishing (glass).
- Hydrogen Cyanide, HCN.—**1. 26.5°. 2. 0.048 (9). 3. 0.012–0.024 (9). 4. 0.005–0.006 (3). 5. 0.002–0.004 (3). 6. Colorless, highly volatile fluid, of penetrating, pungent, and irritating odor. 7. As gas, through the respiratory organs; also through the epidermis. 8. Headache, vertigo, unsteadiness of gait, nausea, loss of appetite, disturbance of gastric and intestinal functions, slowing of the pulse, albuminuria. 9. Manufacture of ammonium salts, celluloid, dyes; acid dipping, blacksmithing, browning (gun barrels), calico printing, case hardening, electroplating, fulminate mixing, gas purifying, gold refining, photog-



raphy, pickling, silver refining, tanning, tempering; work around blast furnaces, and with illuminating gas.

**Hydrogen Sulfide,  $H_2S$  (10).**—1.  $-60.2^\circ$ . 2. 0.06–0.1 (10). 3. 0.05–0.07 (3). 4. 0.02–0.03 (3). 5. 0.01–0.02 (10). 6. Colorless gas with odor of rotten eggs in low concentration; burns with bluish flame forming  $SO_2$  and water; mixed with 7 parts air, explodes with violence when ignited. 7. As gas, through the respiratory organs. 8. Poisoning is of two types—acute and subacute—causing asphyxiation and irritation (conjunctivitis, bronchitis, pharyngitis, and depression of the central nervous system), respectively. In low concentration the symptoms are headache, sleeplessness, dullness, dizziness, and weariness; pain in the eyes, followed by conjunctivitis, is fairly constant; bronchitis and pains in the chest are frequent. Further poisoning produces depression, stupor, unconsciousness and death. Spasms—clonic and tonic—are present. Death from asphyxia is caused by paralysis of respiratory center, while death from subacute poisoning is associated with edema of the lungs. 9. Manufacture of alkali salts, celluloid, dyes, fertilizer, matches, soda, sodium sulfide, starch, artificial silk; bronzing, cable splicing, flax retting, gas purifying, petroleum refining, pyrites burning, sugar refining, tanning; work around blast furnaces; work with glue, illuminating gas, sewers.

**Iodine,  $I_2$  (11).**—1.  $184.35^\circ$ . 4. 0.0003 (3). 5. 0.00005–0.0001 (3). 6. At ordinary temperatures gives off invisible vapor very irritating to the nose and eyes (1). 7. As vapor. 8. Inflammation of the lungs and pulmonary edema. 9. Manufacture of iodine.

**Mercury, Hg.**—1.  $357.33^\circ$ . 5. Less than 0.000125 causes symptoms of poisoning after daily exposure for 2 or 3 months (5). 6. Silver-white, shining metal, unchangeable in air, but evaporating at house temperature (6). 7. Through the uninjured skin, and the respiratory organs in the form of vapor and dust (amalgam dust, dust of the compounds of mercury) (6). 8. Industrial mercurial poisoning is a chronic poisoning occasioned by work in this metal for a long period. The first symptom is generally increased ptyalism, with swelling and inflammation of the gums and of the buccal mucous membrane, often with the formation of rodent ulcers; frequently disturbances of digestion, lassitude and pallor. With further absorption of the metal, "erethism" supervenes—a peculiar psychic excitability (timorousness, bewilderment, irritability), tremor. Death may result in the worst cases in consequence of the violent tremor and spasms affecting the entire body; in other cases increasing weakness (6). 9. Mining and smelting of quicksilver; mirror plating, amalgam gilding and silvering; manufacture of thermometers, barometers, manometers, incandescent electric lamps, Roentgen and Hittorf tubes, mercurial vapor lamps, salts of mercury, amalgams, colors, pharmaceutic products, antiseptic dyes, inflammable materials, explosives; use of mercury salts, especially in the hare's fur business and felt hat manufacture; photography, steel engraving (6).

**Nitrogen Oxides (Expressed in Percentages as Nitric Acid)  $NO$ .**—1.  $-153^\circ$ . 2. 0.07 (12). 3. 0.01 (12). 4. 0.007 (12). 5. 0.0033 (12). 6.  $NO$  is colorless gas readily transformed into brown  $NO_2$  by atmospheric oxygen. 7. As gas, through respiratory organs. 8. Local cauterization of the respiratory tract, leading to laryngitis, bronchitis, hyperemia, hemorrhages and severe edema in addition to vicarious emphysema of the lungs. In men the real illness generally appears only 4 to 6 hours or more after inhalation of the gas; in animals lung edema and a condition threatening to be dangerous ensue promptly (12). 9. Manufacture of aniline, artificial leather, celluloid, dimethyl sulfate, explosives, felt hats, fertilizer, imitation pearls, incandescent lamps, picric acid, soda; dipping, mixing, recovering, transporting acid; bleaching, cartridge dipping, dipping and wringing gun-cotton, enamelling, etching, fur preparing, galva-

nizing, lithography, mining, nitrating, photo-engraving, pickling, metal refining, steel engraving; work with glue, jewelry, mordants, nitric acid, nitroglycerin, sulfuric acid.

**Nitrobenzene,  $C_6H_5NO_2$ .**—1.  $210.9^\circ$ . 4. 0.0001 (3). 5. 0.00002 (3). 6. Colorless, highly refractive fluid having an odor like that of bitter almonds. (All nitro-compounds of benzene have similar properties). 7. As gas, through the respiratory organs. 8. Methemoglobin formation, general debility, anemia, presence of free hematoporphyrin, albumin, and sometimes free poison in the urine; jaundice, gradually becoming cyanosis; skin eruptions, visual disturbances, dyspnea, odor of bitter almonds in breath. 9. Manufacture of aniline, dyes, explosives, perfumes, smokeless powder, soap.

**Phosgene,  $COCl_2$ .**—1.  $8.2^\circ$ . 2. 0.02–0.05 (2). 3. 0.0025 (2). 5. 0.0001 (2). 6. Colorless gas of suffocating odor. 7. As vapor, through the respiratory organs. 8. Destruction of lung tissue, emphysema and edema, myocardial insufficiency due to the emphysema, pleural thickening and adhesions, chronic bronchitis, mild diffuse bronchiectasis, nocturnal dyspnea, polycythemia. 9. Manufacture of dyes, phosgene.

**Phosphorus Trichloride,  $PCl_3$ .**—1.  $76^\circ$ . 2. 0.00035 (3). 3. 0.00003–0.00005 (3). 4. 0.000001–0.000002 (3). 5. 0.0000004 (3). 6. Liquid with sharp smell, fuming in air, and decomposing into phosphorous acid and hydrochloric acid (13). 7. As vapor, through the respiratory organs. 8. Sensation of suffocation, difficulty of breathing, lachrymation, bronchitis, edema and inflammation of the lungs, with frothy, blood-stained expectoration. 9. Manufacture of phosphorus trichloride and organic compounds; use of phosphorus trichloride as chlorinating agent and as solvent of phosphorus.

**Phosphine,  $PH_3$ .**—1.  $-85^\circ$ . 2. 0.2 (14). 3. 0.04–0.06 (3). 4. 0.01–0.02 (3). 6. Colorless gas of nauseating odor. 7. As gas, through the respiratory organs. 8. Oppressed feeling in the chest, headache, vertigo, tinnitus aurium, general debility, loss of appetite, great thirst. 9. Manufacture of acetylene, red phosphorus; phosphorus extracting, work with ferro-silicon.

**Sulfur Dioxide,  $SO_2$ .**—1.  $-10^\circ$ . 2. 0.2 (2). 5. 0.01 (2). 6. Gas with pungent odor and suffocating effect. 7. As gas, through the respiratory organs. 8. Irritation of the mucous membrane of the respiratory organs and eyes, spasmodic cough, bronchial catarrh, digestive disturbances, blood-tinged mucus. 9. Manufacture of alkali salts, bricks, brooms, carbolic acid; work around blast furnaces, brass foundries, sulfuric acid towers; bleaching, zinc charging.

**Sulfur Trioxide,  $SO_3$ .**—2. 0.001 (2). 5. 0.0002 (2). 6. White solid, which evolves dense white fumes on exposure to the air. 7. As gas, through the respiratory organs. 8. Irritation of the respiratory organs, bronchitis. 9. Manufacture of sulfuric acid.

**Toluidine,  $CH_3C_6H_4NH_2$ .**—1.  $200^\circ$ . 4. 0.00025 (3). 5. 0.0001–0.00025 (3). 6. Reddish brown liquid. 7. As vapor, through the respiratory organs. 8. Headache, weakness, difficulty in breathing, cyanosis, convulsions, psychical disturbances, air hunger, marked irritation of the renal organs (13). 9. Manufacture of aniline, coal-tar dyes; tank and still work (13).

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## PREVENTION AND EMERGENCY TREATMENT OF GAS POISONING

### I. Prevention of poisoning

#### A. For all gases

1. Prevention of escape of vapor or fumes into the air of working places.
2. Good ventilation.
3. Testing before entering air suspected of containing poisonous gases.
4. Never entering or working alone in places where the air is known to be contaminated by poisonous gases.
5. Wearing of respirators, gas masks, hose masks, or oxygen breathing apparatus—the latter especially if the air is low in oxygen.
6. Education of workmen regarding the danger of poisoning and methods of prevention.

#### B. For special gases

1. Protection of the skin by suitable clothing and by the application of oils, etc.

In the case of diethylodichloride sulfide (mustard gas), ordinary clothing affords no protection, but cloth painted with linseed oil is adequate. Oiling the skin gives some protection from short exposure to low concentrations of this gas and in high concentrations increases the efficiency of removal-treatment; for long exposure, oils give practically no protection.

2. Abstinence from alcohol, at least during and immediately after labor, especially when exposed to such gases as aniline, toluidine, and nitrobenzene.
3. Scrupulous cleanliness of working places and personally on the part of the workmen.
4. Physical examination of prospective employees to see that they are not suffering from any disease that would make them more susceptible to certain poisonous gases; reexamination of employees at stated intervals (every 30 days for workers in aniline) to detect beginning of poisoning, especially where exposed to fumes of aniline, mercury, and other gases, the action of which is cumulative and danger of acute poisoning is not so great.

### II. Emergency treatment

#### A. For all gases

1. Immediate removal from poisonous atmosphere to fresh air.
2. Immediate administration of artificial respiration (preferably by the Schaefer prone pressure method) if breathing has ceased.
3. Calling a physician.
4. Keeping the patient at rest, lying down (very important).
5. Keeping the patient warm and stimulating circulation by rubbing limbs of patient.

#### B. For special gases

1. Administration of pure oxygen, especially in case of carbon monoxide poisoning.<sup>1</sup>
2. Administration of stimulants: Black coffee, caffeine, camphor, or ether in case of poisoning by aniline, hydrogen cyanide, hydrogen sulfide, phosphine, and toluidine; subcutaneous administration of atropine in poisoning by hydrogen chloride, hydrogen sulfide, and phosphine; hypodermic administration of morphine in poisoning by hydrogen cyanide; inhalation of chloroform in poisoning by phosgene; inhalation of ammonia vapor or soda spray in poisoning by hydrogen chloride, phosgene, phosphorus trichloride, and chloropicrin; infusion of alkaline solution in poisoning by arsine, bromine, iodine, and sulfur dioxide.
3. Venesection is recommended in treatment of poisoning by bromine, chlorine, iodine, nitrogen oxides, phosgene, and chloropicrin, but must not be used after collapse has started.
4. In the case of diethylodichloride sulfide (mustard gas) prevention is especially important as palliative measures are not very successful. The respiratory lesions may be treated by frequent spraying or instillation of a few drops of 1 % sodium bicarbonate, followed by liquid petrolatum and gargling of the throat with a weak Dakin's solution. The eyes should be kept clean by frequent irrigation with a saturated solution of boric acid or with 1 % sodium bicarbonate, followed by a few drops of oil. All clothing should be removed to the skin. Burns of the skin from the vapor should be treated with antiseptics and protected from any irritation. Irritant drugs, such as picric acid or mercuric chloride solutions, should not be applied.

<sup>1</sup> Five per cent carbon dioxide in oxygen, if available, may be administered in carbon monoxide poisoning.

## AIR CONDITIONING

### A. HYGROSCOPIC PROPERTIES OF INDUSTRIAL MATERIALS

D. C. LINDSAY

**Hygroscopic Moisture.**—The moisture contained in a hygroscopic material in equilibrium with the relative humidity of the surrounding atmosphere. The moisture content of a hygroscopic material when in equilibrium depends upon the relative humidity of the surrounding atmosphere but varies widely with different materials. The moisture content also varies to a slight extent with different temperatures at the same humidity. Hygroscopic moisture in materials is in most industries termed "*regain*," and is expressed in parts of water per 100 parts of dry material.

**Hygroscopic Properties of Materials.**—The hygroscopic properties of materials vary widely from one another and even in the same material a wide variation is frequently observed, and is dependent upon the prior history of the material. The curves given below

are based upon a critical study of available data. Qualitatively, they are correct and can be used where extreme accuracy is not required. Consistency in form will be noted in all cases. For the accurate determination of hygroscopic characteristics of materials, the use of insulated cabinets provided with air circulation and automatic instruments (<sup>10</sup>) for controlling temperature and humidity are recommended as being superior to the taking of such data, within a stagnant atmosphere, the moisture equilibrium of which is maintained by hygroscopic solutions such as sulfuric acid.

**Electrostatic Condition of the Atmosphere**—Electrical charges are dissipated at normal temperatures (18 to 30°C) at a relative humidity of 50 % or above.

This is of extreme importance in textile mills and printing plants where the charged atmosphere prevalent during the winter causes bristling of the fibers and hampers operations.

The elimination of static by humidification has been successfully applied to reduce explosion hazards in munition plants and other explosive atmospheres.

**Mildew Fungi.**—These will thrive in relatively still atmosphere only at relative humidities above 75 %.

FAVORABLE CONDITIONS OF TEMPERATURE AND HUMIDITY ARTIFICIALLY CREATED AND MAINTAINED IN MANUFACTURING PROCESSES

Industry and product	Process	Temp., °C	Relative humidity, %
Cotton.....	Carding.....	20 to 23	50
	Combing.....	20 to 23	60-65
	Roving.....	20 to 23	50-60
	Spinning.....	20 to 23	60-65
	Spooling, twisting.....	20 to 23	65
	Warping.....	20 to 23	65
	Weaving.....	20 to 23	75-80
Wool.....	Carding.....	23 to 25	65-70
	Spinning.....	23 to 25	55-60
	Weaving.....	20 to 23	50-55
	Storage for shipping.....	20 to 23	55-60
Silk.....	Dressing.....	21 to 25	60-65
	Spinning.....	21 to 25	65-70
	Throwing.....	21 to 25	65-70
	Weaving.....	21 to 25	60-70
Confectionery	Chocolate enrobing.....	18	≥ 55
	Hard candy making.....	21	≥ 50
	Storage.....	- 1 +15*	≥ 70 ≥ 55
Tobacco.....	Softening.....	29	85
	Cigar and cigarette making	21 to 23	55-70
Printing.....	Lithographing.....	21	45
	Relief and offset.....	25	45
	Folding.....	25	65
	Binding.....	21	45
Baking.....	Dough fermentation.....	27	65
	Proofing.....	32 to 35	80-90
	Loaf cooling.....	21	65
Electrical cable	Winding insulation.....	≥ 40	≥ 5
Cellulose lacquers.....	Application.....	24	≥ 20
Munitions.....	Fuse loading.....	21	55
Cereals.....	Seal packing prepared, crisp cereals.....	23	45-50

\* Divergence in practice.

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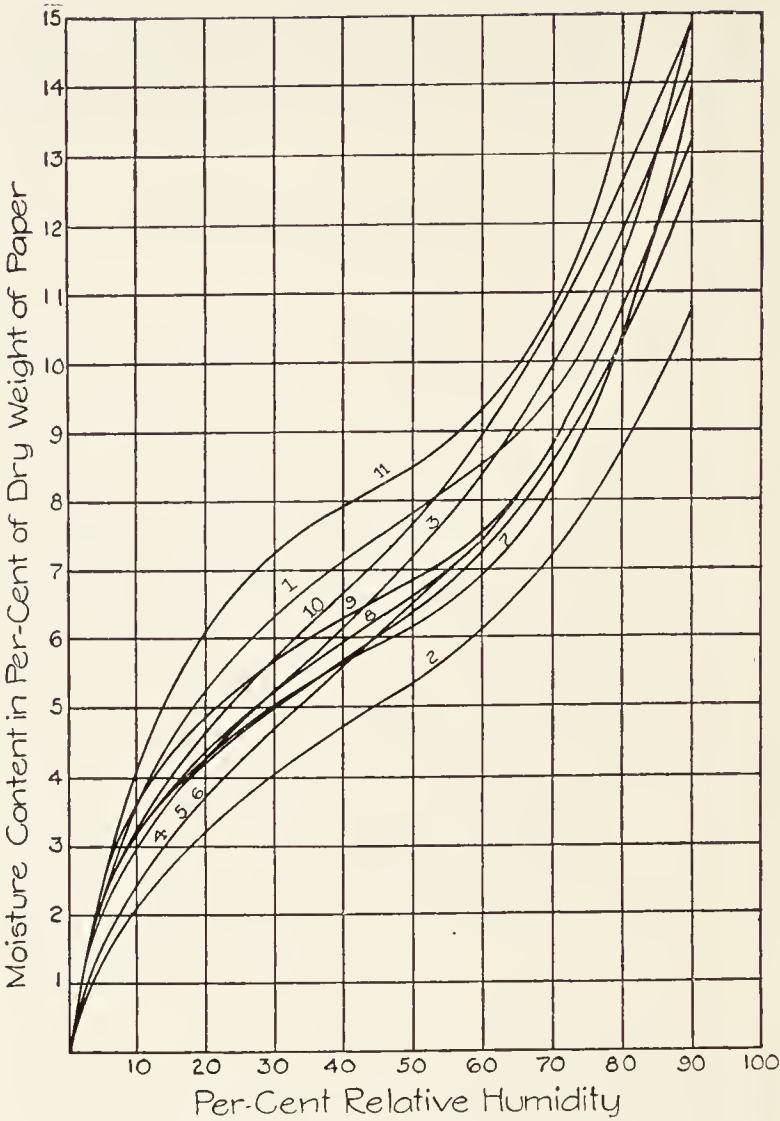


FIG. 1.—Hygroscopic moisture of various papers (cf. (2, 3, 6, 7, 11)).

Curve No.	Description	Ash, %	Rosin, %	Rag, %	Chemical wood bleached, %	Coniferous, %	Manila and jute, %	Lit.
1	Sulfite cellulose pulp.....							(3, 11)
2	News print.....	24.4	1.0		100			(6)
3	Writing.....	2.9	2.2		100			(6)
4	Fine white writing.....	0.8	1.2	100				(6, 7)
5	White bond.....	1.0	1.0	100				(6)
6	Fine white bond.....	0.2	1.0	100				(6)
7	Commercial ledger.....	0.6	1.7	75	25			(6)
8	White ledger.....	0.9	1.2	100				(6)
9	Index bristol.....	1.0	1.7	50	50			(6)
10	Kraft wrapping.....	0.3	1.3			100		(6)
11	Rope manila.....	1.6	1.5				75	(6)

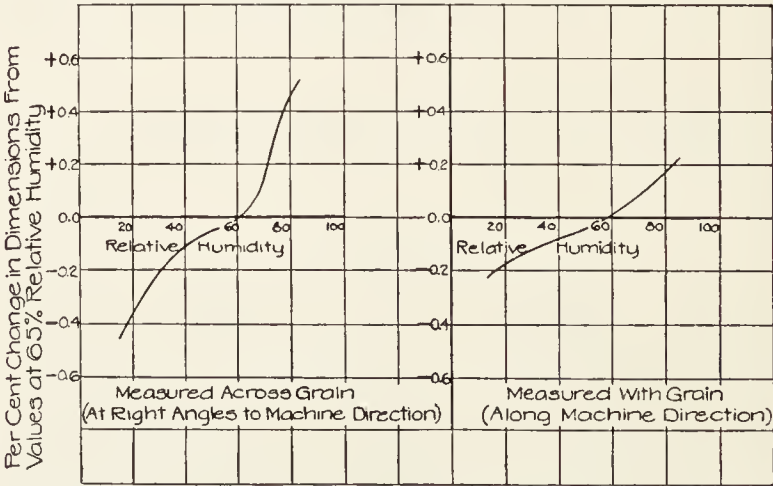


FIG. 2.—Composite curves for all papers in Fig. 1. Variation in dimensions with variation in relative humidity.



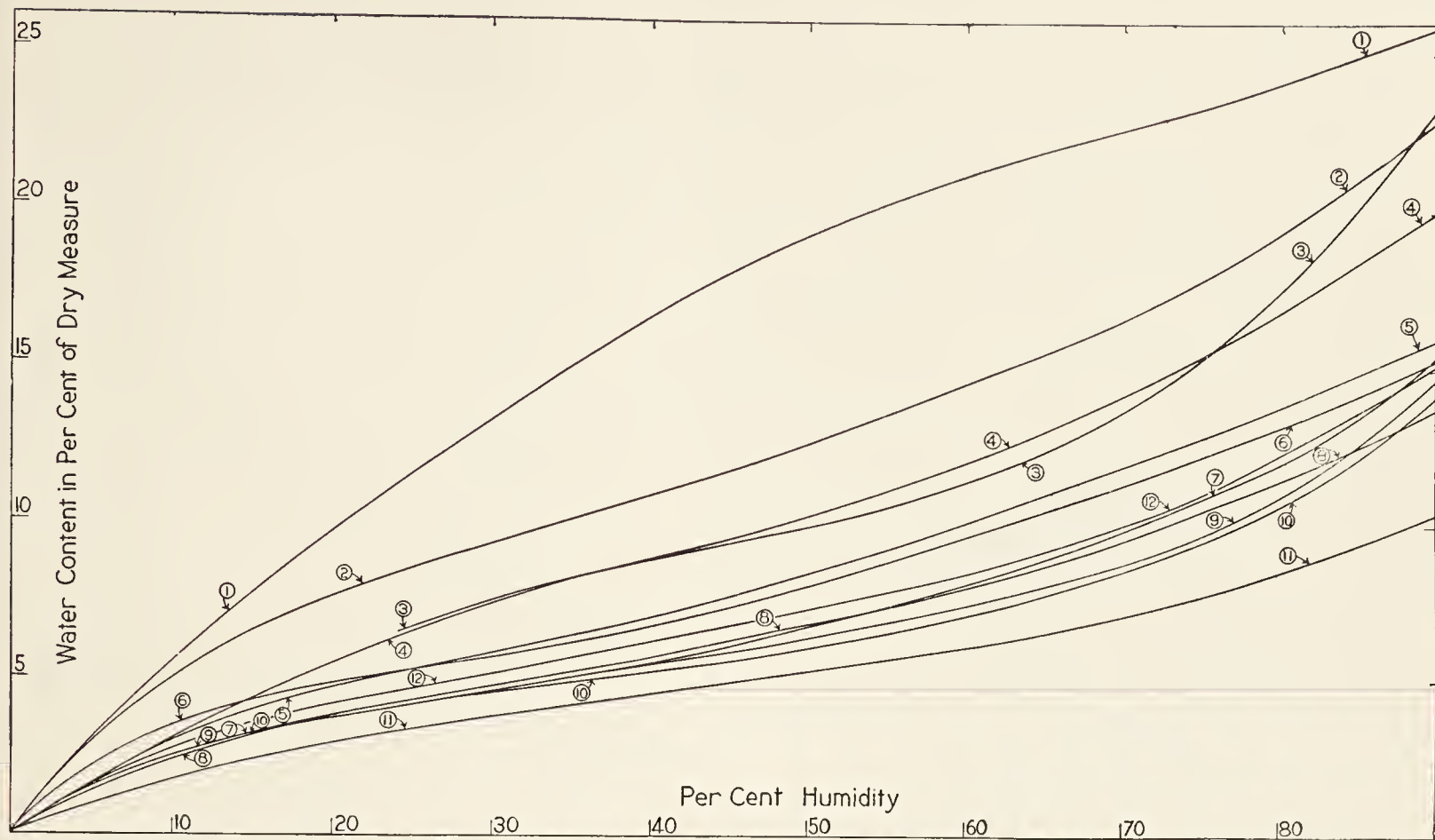


FIG. 3.—Hygroscopic moisture of natural fiber textile materials (3, 5, 12, 14).

Curve No.	Material	Curve No.	Material
1	Absorbent cotton	7	Indian cotton
2	Wool, worsted	8	Cotton cloth
3	Silk, new yellow	9	Egyptian cotton

Curve No.	Material	Curve No.	Material
4	Jute	10	American cotton
5	Manila hemp	11	Linen
6	Sisal hemp	12	Flax

All observations at approx. 25°C.

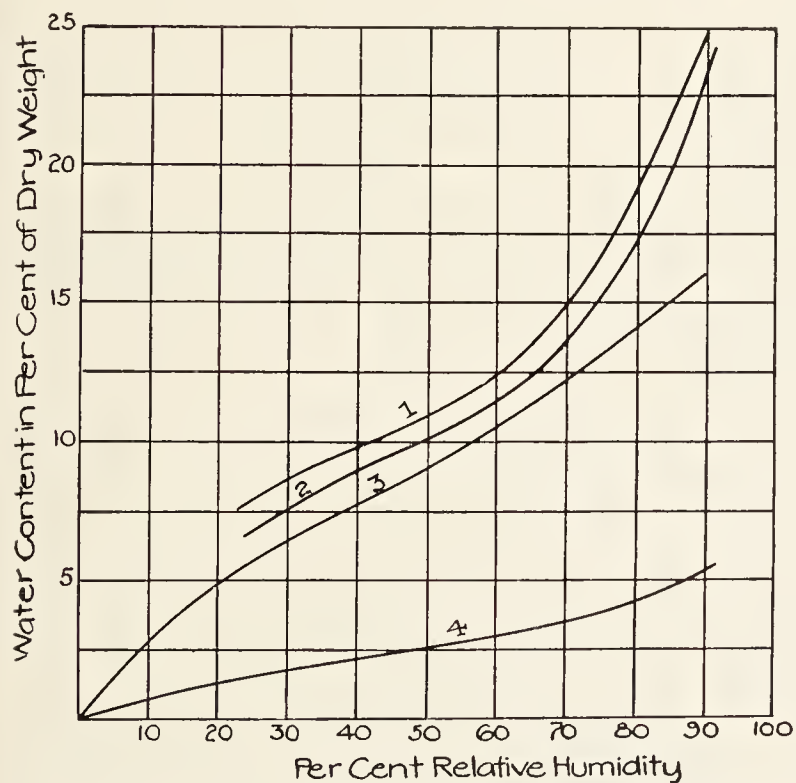


FIG. 4.—Hygroscopic moisture of artificial textile fibers compared with crude constituents and natural silk (3, 14).

Curve No.	Material
1	Viscose rayon (artificial silk)
2	Natural silk, new yellow
3	Nitrocellulose
4	Cellulose acetate

All observations at approx. 25°C.

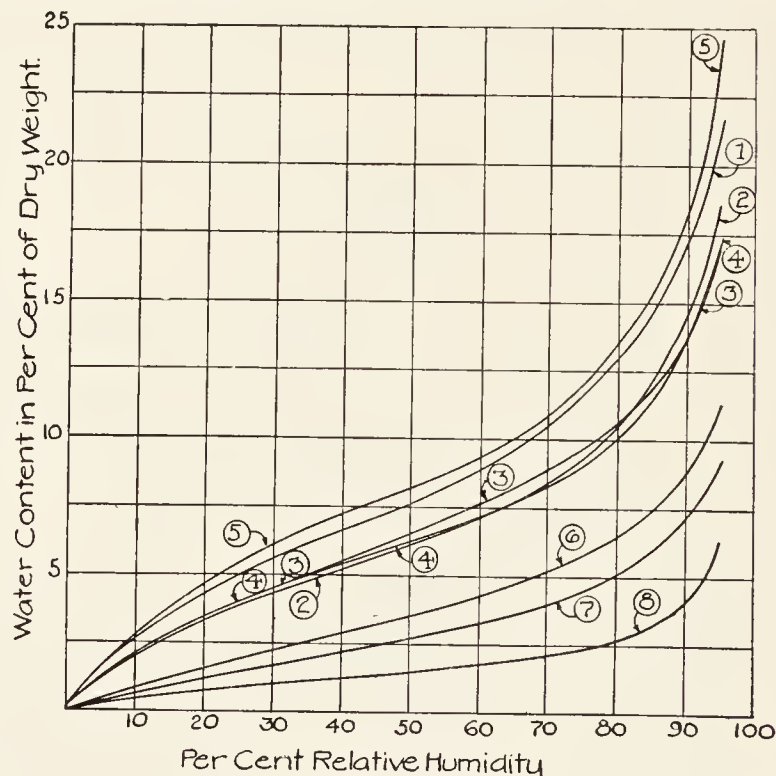


FIG. 6.—Hygroscopic moisture of various fibrous materials prepared for electrical insulation (8, 9).

Curve No.	Material
1	Manila paper
2	Red rope paper
3	Press board
4	Leatheroid paper
5	Silk
6	Red rope paper (varnished)
7	Empire cloth
8	Asbestos paper

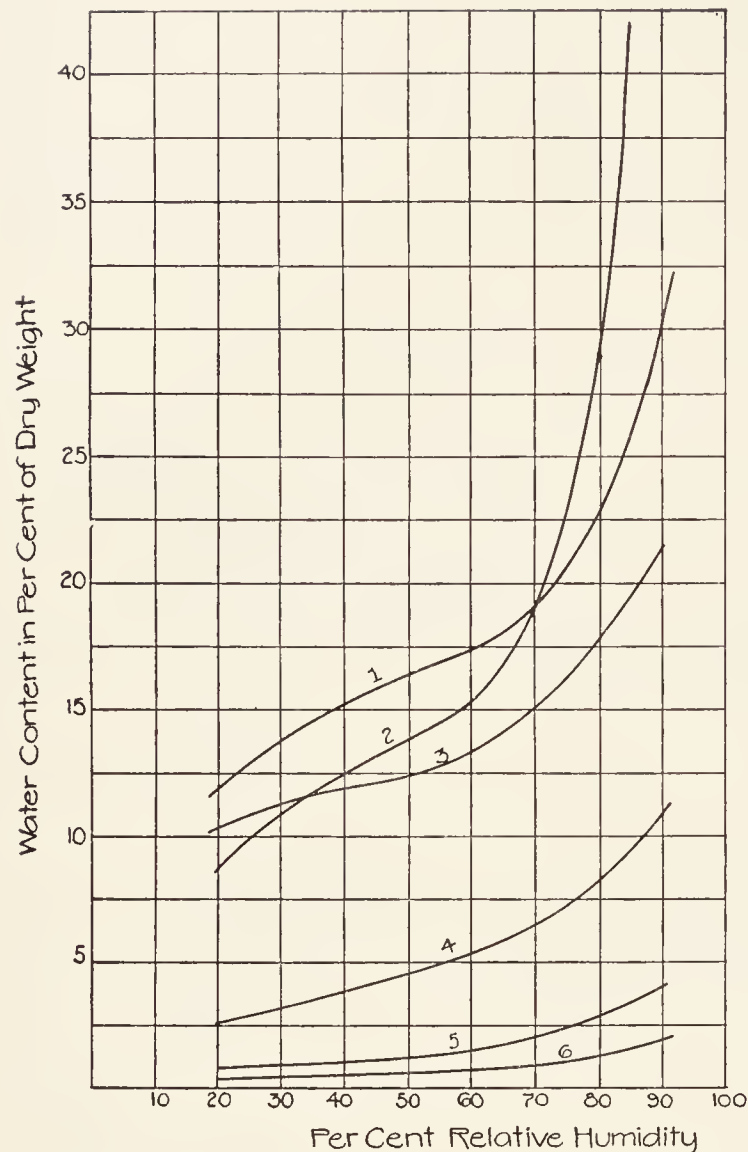


FIG. 5.—Hygroscopic moisture of leather and rubber (3).

Curve No.	Material
1	Leather (sole oak tanned)
2	Sheepskin
3	Gold beater skin
4	Latex, dipped cord
5	Reclaimed rubber
6	Smoked, crepe sheet

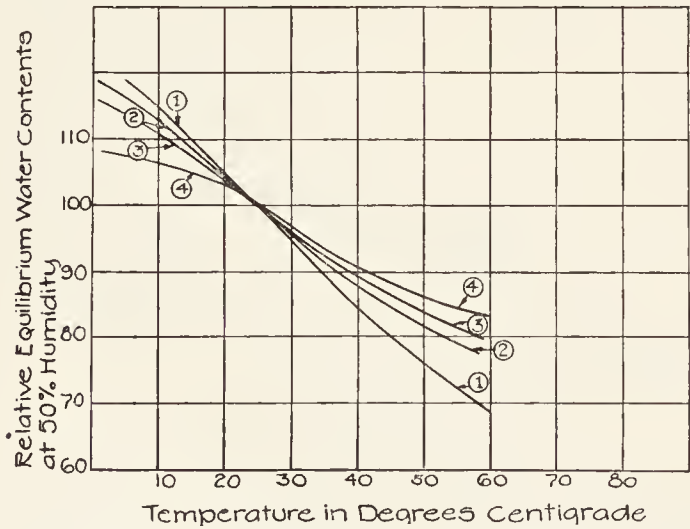


FIG. 11.—Effect of varying temperature on equilibrium water content at constant relative humidity of 50 % (14).

Curve No.	Material
1	Wood
2	Silk
3	Wool
4	Cotton

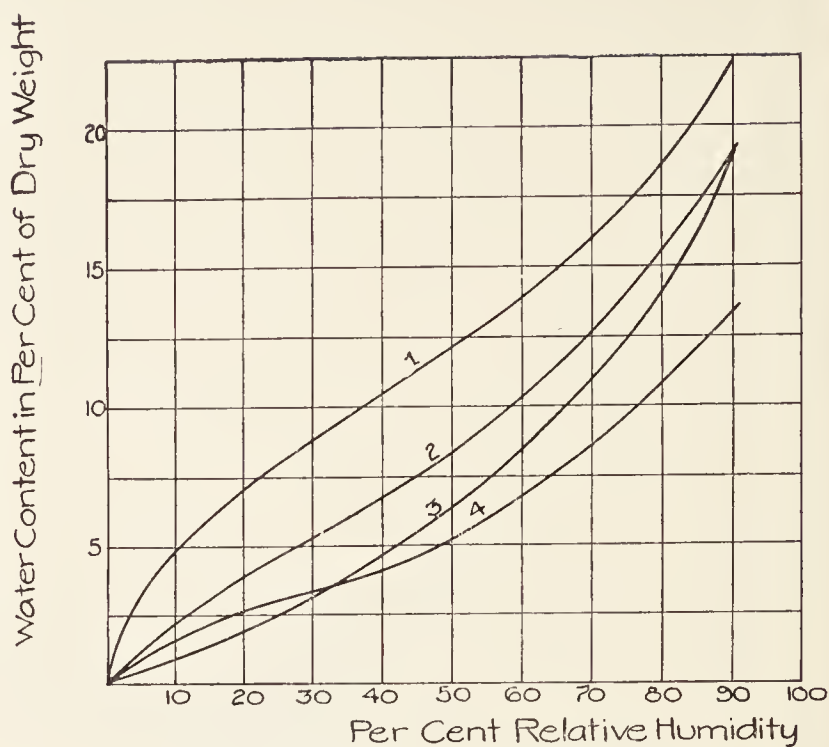


FIG. 7.—Hygroscopic moisture of cereal foods (1, 3, 14).

Curve No.	Material
1	Macaroni
2	Flour (patent)
3	Bread
4	Crackers

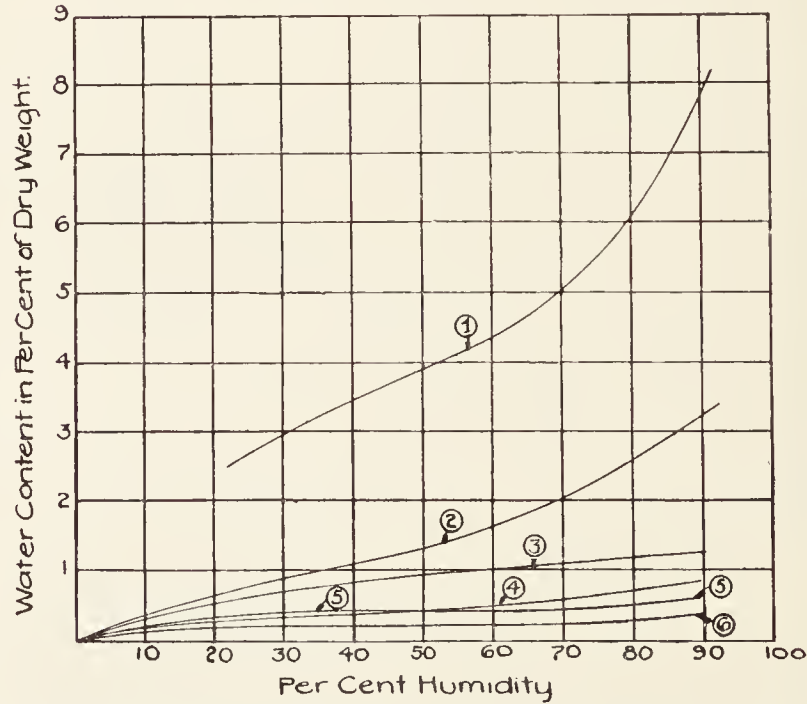


FIG. 8.—Hygroscopic moisture of some inorganic substances (10, 14).

Curve No.	Material
1	English ball clay
2	Kieselguhr
3	Kaolin
4	Asbestos fiber
5	Zinc oxide
6	Glass wool



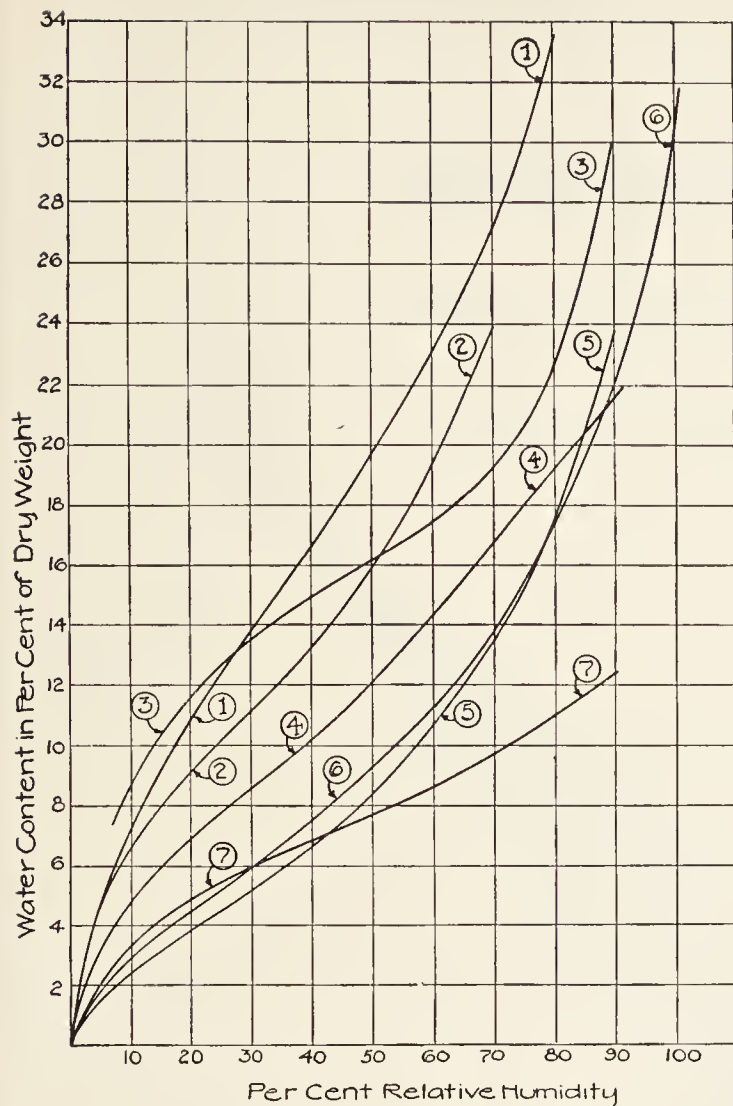


FIG. 9.—Hygroscopic moisture of some organic substances.

Curve No.	Material	Lit.
1	North Carolina leaf tobacco	(3)
2	Cigarette tobacco (Fatima)	(14)
3	Sole leather (oak tanned)	(3)
4	Catgut	(14)
5	Soap (Ivory)	(14)
6	Lumber*	(4)
7	Glue (hide, first grade)	(14)

\* All species of timber have been found to have approximately the same values at given relative humidities. Rate of absorption or evaporation from timbers varies according to the density of the species.

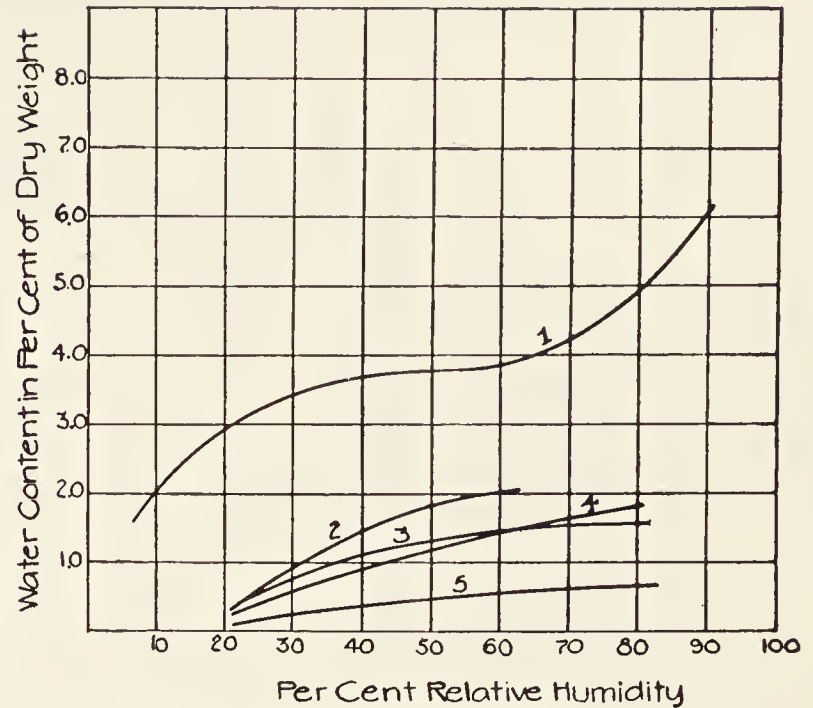


FIG. 10.—Hygroscopic moisture of carbon products (13, 14).

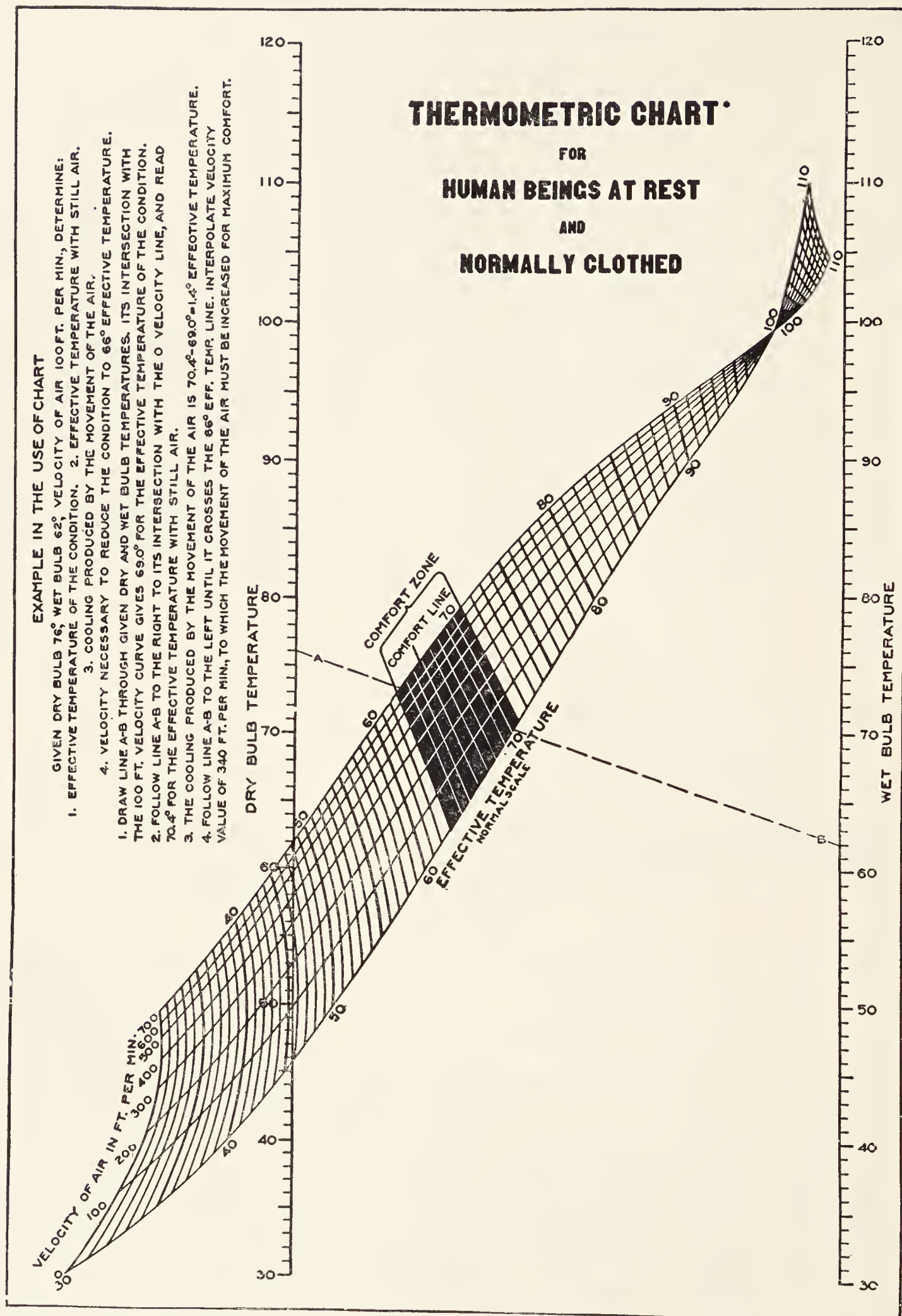
Curve No.	Material
1	Carbon black for rubber trade
2	By-product furnace coke (Franklin Co., Ill., coal)
3	By-product coke, domestic size (Pittsburgh bed coal)
4	By-product coke (domestic size)
5	Connellsville, 72 hour bee-hive foundry coke

## B. SPACES OCCUPIED BY HUMAN BEINGS

R. R. SAYERS

### EFFECTS OF TEMPERATURE AND HUMIDITY ON HUMAN BEINGS IN STILL AIR

Temperature of air, relative humidity 100 %	Effects when at rest				Effects when at moderate work		
	Pulse rate	Body temperature	Metabolism	Remarks	Pulse rate	Body temperature	Remarks
°F							
98	Greatly increased	Marked increase	Marked increase	Very hot, even with little clothing	Very rapid	Marked increase	Very hot
95	Marked increase	Increased	Increased	Hot, even when little clothing worn	Very rapid	Marked increase	Very hot
90	Increased	Increased	Increased	Very warm	Rapid	Increased	Hot
85	No change	No change	Slight increase	Warm	Increased	Slight increase	Very warm
75-80	Slight decrease	Slight decrease	Minimum metabolism	Comfortable	Slight increase	Slight increase	Comfortable or warm
65-70	Decrease	Slight decrease	Slight increase	Slightly cool to comfortable	Slight increase	Slight increase	Comfortable
55-60	Decrease	Slight decrease	Slight increase	Cool, clothing needed for comfort	Slight increase	Slight increase	Comfortable to cool
45-50	Decrease	Slight decrease	Increased	Cool, clothing needed for comfort	Slight increase	Slight increase	Cool



\* Jour. Am. Soc. of Heat. and Vent. Eng., 31: 66, 25.



## REFRIGERATING BRINES

R. S. JESSUP

**Aqueous Solutions.**—All data are based upon weight *in vacuo*.  
 $p$  = wt. % anhyd. salt,  $t$  = °C,  $d$  = gram per milliliter,  $\eta$  = viscosity in centipoise,  $c$  = heat capacity under atmos. pressure.

For other data see sections of I. C. T. on the properties of salt solutions.

## DENSITY AND SPECIFIC GRAVITY

## Conversion Factors

1 g ml<sup>-1</sup> = 0.999973 g cm<sup>-3</sup> = 0.036126 lb. in.<sup>-3</sup> = 62.426 lb. ft.<sup>-3</sup> = 8.34523 lb. gal.<sup>-1</sup> (U. S.) = 10.0221 lb. gal.<sup>-1</sup> (Brit.).

## SODIUM CHLORIDE, NaCl

$d_4^{25}$  = sp. gr. = [(0.99707 + 0.0070033 $p$  + 14.059 × 10<sup>-6</sup> $p^2$  + 330.9 × 10<sup>-9</sup> $p^3$ ) ± 0.005%] g ml<sup>-1</sup>. Range, 5–25% (3, 4, 15, 20, 25).

1/ $d_t$  = 1/ $d_0$  (1 +  $at$  +  $bt^2$  -  $ct^3$ ) ± 0.005 % (20) whose values check those of (14, 27, 29, 30).

$d_t \pm < 0.01$  %.

$p$	-20°C	-10°C	0°C	10°C	20°C	30°C	$a \times 10^4$	$b \times 10^6$	$c \times 10^9$
5			1.03820	1.03659	1.03405	1.03074	1.0685	5.1425	21.750
6			1.04590	1.04403	1.04131	1.03786	1.3380	4.7100	19.000
7			1.05361	1.05150	1.04860	1.04503	1.5879	4.3162	16.547
8			1.06133	1.05900	1.05594	1.05225	1.8235	3.9350	14.000
9			1.06909	1.06654	1.06332	1.05951	2.0394	3.6062	12.047
10			1.07680	1.07411	1.07074	1.06682	2.2409	3.3037	10.297
11			1.08467	1.08173	1.07821	1.07417	2.4272	3.0362	8.875
12			1.09251	1.08939	1.08572	1.08158	2.6001	2.7962	7.703
13			1.10039	1.09709	1.09329	1.08904	2.7613	2.5725	6.578
14			1.10830	1.10483	1.10090	1.09656	2.9260	2.2575	5.370
15	1.11945	1.11626	1.11262	1.10857	1.10413	3.0629	2.0937	3.297	
16	1.12765	1.12427	1.12047	1.11630	1.11177	3.1936	1.9187	2.453	
17	1.13588	1.13232	1.12838	1.12409	1.11946	3.3127	1.7725	1.922	
18	1.14415	1.14041	1.13634	1.13193	1.12722	3.4253	1.6300	1.328	
19	1.15246	1.14857	1.14436	1.13984	1.13504	3.5290	1.5100	1.000	
20	1.16082	1.15678	1.15244	1.14782	1.14293	3.6237	1.4125	0.922	
21	1.16923	1.16505	1.16058	1.15586	1.15089	3.7129	1.3187	0.797	
22	1.17770	1.17337	1.16880	1.16397	1.15891	3.7950	1.2375	0.750	
23	1.19044	1.18622	1.18176	1.17707	1.17215	3.8717	1.1337		
24	1.19480	1.19022	1.18542	1.18040	1.17519	3.9425	1.0675		
25		1.19874	1.19383	1.18873	1.18344	4.0090	1.0050		

CALCIUM CHLORIDE, CaCl<sub>2</sub>

$d_4^0$  = sp. gr. = [(0.99987 + 0.0086417 $p$  + 29.17 × 10<sup>-6</sup> $p^2$  + 321.3 × 10<sup>-9</sup> $p^3$ ) ± 0.03%] g ml<sup>-1</sup> (6).

$d_t = (d_0 - at - bt^2) \pm 0.05\%$  (23.5).

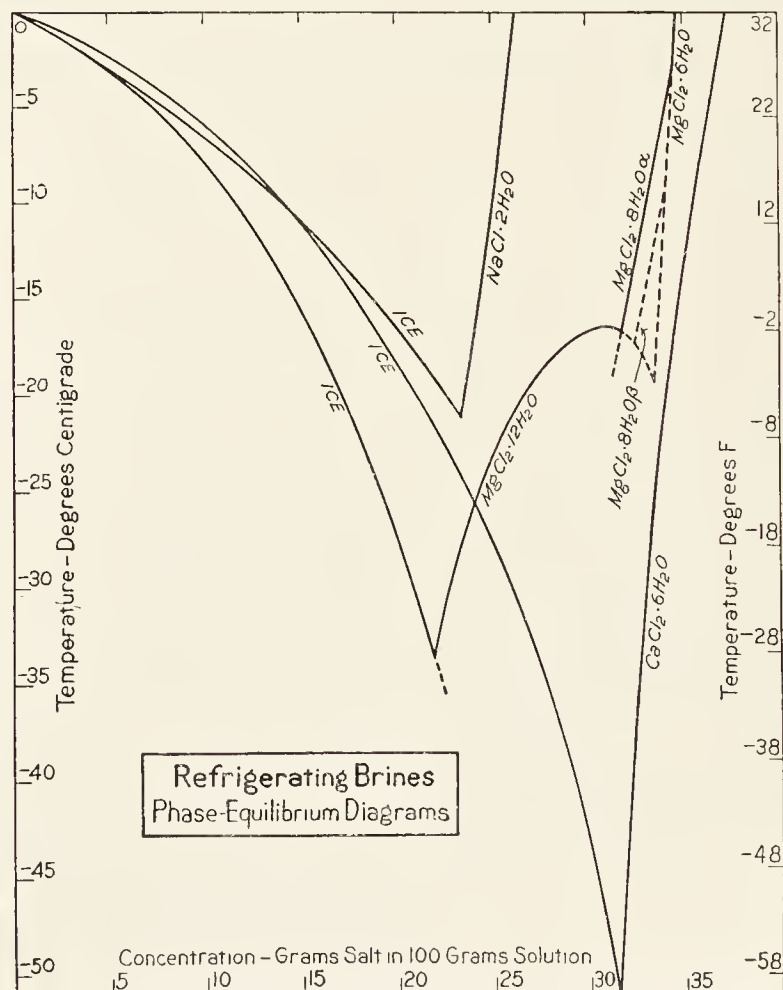
$p$	-30°	-20°	-10°	0°	10°	20°	30°	$a \times 10^6$	$b \times 10^6$
5				1.0438	1.0425	1.0402	1.0369	80	5.0
6				1.0528	1.0513	1.0489	1.0456	105	4.5
7				1.0619	1.0602	1.0577	1.0544	130	4.0
8				1.0710	1.0691	1.0664	1.0629	150	4.0
9				1.0802	1.0781	1.0753	1.0718	175	3.5
10				1.0895	1.0872	1.0843	1.0808	200	3.0
11				1.0989	1.0964	1.0934	1.0899	225	2.5
12				1.1083	1.1056	1.1025	1.0993	250	2.0
13				1.1178	1.1150	1.1117	1.1079	255	2.5
14				1.1274	1.1244	1.1210	1.1172	280	2.0
15			1.1396	1.1371	1.1340	1.1304	1.1261	278	2.8
16			1.1496	1.1469	1.1438	1.1399	1.1357	297	2.6
17			1.1597	1.1568	1.1534	1.1495	1.1451	315	2.5
18			1.1698	1.1667	1.1632	1.1592	1.1548	332	2.2
19			1.1801	1.1768	1.1731	1.1690	1.1645	350	2.0
20			1.1904	1.1869	1.1831	1.1788	1.1742	368	1.8
21		1.2046	1.2010	1.1972	1.1932	1.1889	1.1844	392	1.2
22		1.2150	1.2114	1.2075	1.2033	1.1989	1.1942	403	1.3
23		1.2260	1.2221	1.2180	1.2137	1.2092	1.2045	420	1.0
24		1.2369	1.2328	1.2285	1.2240	1.2194	1.2146	438	0.8
25		1.2481	1.2437	1.2392	1.2346	1.2299	1.2251	455	0.5
26	1.2634	1.2590	1.2545	1.2499	1.2452	1.2403	1.2354	467	0.6
27	1.2749	1.2703	1.2656	1.2608	1.2559	1.2510	1.2460	483	0.4
28	1.2868	1.2818	1.2768	1.2718	1.2668	1.2617	1.2567	502	0.1
29	1.2981	1.2930	1.2879	1.2828	1.2777	1.2725	1.2674	512	0.1
30	1.3098	1.3045	1.2993	1.2940	1.2888	1.2835	1.2783	525	0

MAGNESIUM CHLORIDE, MgCl<sub>2</sub>

$d_4^0$  = sp. gr. = [(0.99987 + 0.008652 $p$  + 16.26 × 10<sup>-6</sup> $p^2$  + 487.7 $p^3$ ) × 10<sup>-9</sup> ± 0.03%] g ml<sup>-1</sup> (6).

$d_t = (d_0 - at - bt^2) \pm 0.05\%$  (23.5).

$p$	-30°	-20°	-10°	0°	10°	20°	30°	$a \times 10^6$	$b \times 10^6$
5				1.0436	1.0426	1.0404	1.0372	50	5.5
6				1.0525	1.0513	1.0491	1.0459	70	5.0
7				1.0614	1.0600	1.0577	1.0545	95	4.5
8				1.0704	1.0689	1.0665	1.0633	105	4.5
9				1.0794	1.0778	1.0753	1.0719	115	4.5
10				1.0885	1.0867	1.0842	1.0807	145	3.5
11				1.0977	1.0958	1.0932	1.0899	155	3.5
12			1.1083	1.1069	1.1049	1.1022	1.0989	172	3.1
13			1.1177	1.1162	1.1141	1.1114	1.1081	180	3.0
14			1.1272	1.1255	1.1233	1.1205	1.1173	197	2.6
15			1.1368	1.1350	1.1327	1.1299	1.1266	205	2.5
16			1.1465	1.1445	1.1421	1.1392	1.1360	222	2.1
17			1.1561	1.1540	1.1515	1.1486	1.1453	230	2.0
18		1.1677	1.1659	1.1637	1.1611	1.1582	1.1549	238	1.8
19		1.1778	1.1758	1.1735	1.1709	1.1679	1.1647	247	1.6
20		1.1878	1.1857	1.1833	1.1806	1.1776	1.1743	255	1.5
21	1.1995	1.1977	1.1956	1.1932	1.1905	1.1874	1.1840	258	1.6
22	1.2099	1.2080	1.2058	1.2033	1.2005	1.1974	1.1940	264	1.5
23		1.2186	1.2161	1.2134	1.2105	1.2074	1.2041	280	1.0
24		1.2289	1.2263	1.2236	1.2206	1.2175	1.2142	285	1.0
25		1.2393	1.2367	1.2339	1.2310	1.2278	1.2245	288	0.8
26		1.2500	1.2473	1.2444	1.2413	1.2381	1.2347	298	0.8
27			1.2578	1.2549	1.2518	1.2486	1.2452	298	0.8
28			1.2686	1.2656	1.2625	1.2592	1.2558	307	0.7
29			1.2794	1.2763	1.2731	1.2698	1.2664	315	0.5
30			1.2903	1.2872	1.2840	1.2807	1.2773	315	0.5



## HEAT CAPACITY (SPECIFIC HEAT)

## Conversion Factors

1 joule g<sup>-1</sup> per °C = 0.2389 g-cal<sub>15</sub> g<sup>-1</sup> per °C or BTU<sub>60</sub> lb.<sup>-1</sup> per °F  
 = 2.778 × 10<sup>-7</sup> kw-hr g<sup>-1</sup> per °C

1 joule cm<sup>-3</sup> per °C = 1.994 BTU<sub>60</sub> gal.<sup>-1</sup> per °F (U. S.)  
 = 2.394 BTU<sub>60</sub> gal.<sup>-1</sup> per °F (Brit.)

## SODIUM CHLORIDE, NaCl

$c_{20} = [0.6516 + (0.3475)(0.96285)^p]$  cal<sub>15</sub> g<sup>-1</sup> per °C;  $c_t = [c_{20} + a(t - 20) - b(t - 20)^2]$  cal<sub>15</sub> g<sup>-1</sup> per °C (2).

p	Joule per gram per °C ± 0.1 %					a × 10 <sup>4</sup>	b × 10 <sup>6</sup>
	-10°	0°	10°	20°	30°		
5		3.911	3.921	3.931	3.940	2.3	0
6		3.862	3.874	3.886	3.896	2.6	-1
7		3.816	3.830	3.843	3.854	2.8	-2
8		3.771	3.787	3.801	3.813	3.0	-3
9		3.730	3.747	3.761	3.772	3.0	-4
10		3.689	3.708	3.723	3.734	3.1	-5
11		3.651	3.670	3.686	3.697	3.2	-5
12		3.615	3.635	3.650	3.661	3.2	-5
13		3.580	3.600	3.615	3.627	3.2	-5
14		3.547	3.567	3.583	3.593	3.1	-6
15	3.491	3.516	3.536	3.551	3.561	3.0	-6
16	3.463	3.487	3.506	3.520	3.530	2.8	-6
17	3.435	3.458	3.477	3.491	3.500	2.7	-6
18	3.409	3.432	3.450	3.463	3.471	2.5	-6
19	3.384	3.406	3.423	3.435	3.443	2.3	-6
20	3.361	3.382	3.398	3.409	3.415	2.0	-6
21	3.338	3.358	3.374	3.384	3.389	1.8	-6
22	3.318	3.337	3.351	3.359	3.363	1.5	-6
23*	3.298	3.315	3.328	3.336	3.340	1.5	-5
24	3.279	3.295	3.306	3.313	3.316	1.2	-5
25	3.261	3.276	3.286	3.292	3.293	0.9	-5

\* For p = 23; c = 3.277 at -20°.

CALCIUM CHLORIDE, CaCl<sub>2</sub>

$c_0 = [(1.0138 - 0.018091p + 197.34 \times 10^{-6}p^2) + 0.002]$  cal<sub>15</sub> g<sup>-1</sup> per °C (10).

$c_t = (c_0 + at + bt^2) \pm 0.002$  cal<sub>15</sub> g<sup>-1</sup> per °C.

p	Joule per gram per °C							a × 10 <sup>4</sup>	b × 10 <sup>6</sup>
	-40°	-30°	-20°	-10°	0°	10°	20°		
8					3.691	3.712	3.733	3.754	5.0
9					3.628	3.649	3.670	3.691	5.0
10					3.570	3.591	3.612	3.633	5.2
11					3.511	3.532	3.553	3.578	5.4
12					3.453	3.478	3.500	3.524	5.5
13					3.398	3.423	3.444	3.469	5.7
14					3.344	3.369	3.393	3.419	5.9
15					3.294	3.319	3.344	3.369	6.0
16				3.214	3.243	3.268	3.294	3.315	6.8
17				3.164	3.193	3.222	3.243	3.264	6.9
18				3.118	3.147	3.176	3.197	3.218	7.0
19				3.072	3.101	3.130	3.155	3.176	7.1
20				3.026	3.059	3.089	3.114	3.135	7.1
21				2.984	3.017	3.047	3.068	3.093	7.2
22			2.909	2.946	2.976	3.005	3.030	3.051	7.3
23			2.871	2.904	2.938	2.967	2.992	3.017	7.4
24			2.837	2.871	2.900	2.930	2.955	2.980	7.2
25			2.804	2.837	2.867	2.896	2.921	2.946	7.0
26		2.745	2.775	2.804	2.833	2.858	2.888	2.912	6.7
27		2.716	2.745	2.775	2.800	2.829	2.854	2.883	6.6
28	2.662	2.687	2.716	2.745	2.770	2.800	2.825	2.854	6.5
29	2.653	2.674	2.695	2.716	2.741	2.770	2.796	2.825	6.0
30	2.641	2.657	2.670	2.691	2.716	2.741	2.766	2.796	5.7

MAGNESIUM CHLORIDE, MgCl<sub>2</sub>

$c_0 = [(1.00070 - 0.016746p + 144.9 \times 10^{-6}p^2) \pm 1\%]$  cal<sub>15</sub> g<sup>-1</sup> per °C (23).  $c_t = (c_0 + at)$  cal<sub>15</sub> g<sup>-1</sup> per °C (23).

p	Joule per gram per °C							a × 10 <sup>4</sup>
	-30°	-20°	-10°	0°	10°	20°	30°	
5				3.879	3.888	3.896	3.905	1.9
6				3.817	3.825	3.838	3.846	2.4
7				3.754	3.767	3.779	3.787	2.8
8				3.691	3.704	3.720	3.733	3.3

MAGNESIUM CHLORIDE, MgCl<sub>2</sub>.—(Continued)

p	Joule per gram per °C							a × 10 <sup>4</sup>
	-30°	-20°	-10°	0°	10°	20°	30°	
9				3.633	3.649	3.662	3.679	3.7
10				3.574	3.591	3.607	3.624	4.1
11				3.515	3.536	3.553	3.573	4.5
12			3.440	3.461	3.482	3.503	3.520	4.8
13			3.386	3.407	3.428	3.448	3.474	5.2
14			3.327	3.352	3.373	3.398	3.419	5.5
15			3.273	3.297	3.323	3.348	3.369	5.8
16		3.197	3.222	3.248	3.273	3.297	3.323	6.0
17		3.147	3.172	3.197	3.222	3.248	3.277	6.2
18		3.093	3.122	3.147	3.172	3.202	3.227	6.3
19		3.047	3.076	3.101	3.126	3.155	3.181	6.4
20	2.976	3.001	3.030	3.055	3.084	3.109	3.139	6.5
21	2.930	2.955	2.984	3.009	3.038	3.063	3.093	6.5
22		2.912	2.938	2.967	2.992	3.022	3.047	6.5
23		2.871	2.896	2.921	2.950	2.976	3.005	6.5
24		2.829	2.854	2.883	2.909	2.938	2.963	6.5
25		2.787	2.817	2.842	2.867	2.896	2.921	6.4
26		2.750	2.779	2.804	2.829	2.858	2.883	6.4
27		2.708	2.737	2.762	2.787	2.817	2.842	6.3
28			2.699	2.729	2.754	2.779	2.808	6.2
29			2.666	2.691	2.716	2.741	2.766	6.1
30			2.632	2.657	2.683	2.708	2.733	6.0

## VISCOSITY

Data for low temperatures, very meager. The information available is expressed by the following equations and tables: (cf. I. C. T. sections on viscosity of H<sub>2</sub>O and salt solutions).

NaCl,  $\eta = [(\eta_w + ap + bp^2) \pm 0.5\%]$ . Range, 0–30° and 5–20% (18, 19, 32, 37).

CaCl<sub>2</sub>,  $\log \eta = [(\log \eta_w + ap + bp^2) \pm 3\%]$ . Range 10–30°, 5–30% (37).

For p = 30.89%,  $\eta = [(0.1392 + 0.004815t + 47.27 \times 10^{-6}t^2) \pm 5\text{--}10\%]$ . Range, -50 to 30° (39).

MgCl<sub>2</sub>,  $\eta_{25} = 0.895 + 0.0339p + 900 \times 10^{-6}p^2 + 82.14 \times 10^{-6}p^3$ . Range 0–22%. Precision ± 0.5%. Accuracy ? (18, 41).

		0°	5°	10°	15°	20°	25°	30°
CaCl <sub>2</sub>	a × 10 <sup>3</sup> =			113.94	54.61	0	-47.69	-95.83
	b × 10 <sup>3</sup> =			6.0996	6.4427	6.8451	7.0553	7.6747
	c × 10 <sup>6</sup> =			380.50	381.31	375.85	370.27	352.68
	21.56% $\eta =$		3.113(17)	2.729(17)	2.412(17)			
NaCl	a × 10 <sup>3</sup> =	4.90	9.20	10.65	10.90	10.70	10.20	9.75
	b × 10 <sup>3</sup> =	1.930	1.410	1.125	0.930	0.790	0.690	0.605
0%	$\eta_w =$	1.794	1.519	1.310	1.145	1.009	0.895	0.800
	20% $\eta =$	2.663	2.269	1.973	1.733	1.538	1.376	1.240

## LITERATURE

(For a key to the periodicals see end of volume)

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## SIEVES AND SCREENS

LEWIS V. JUDSON

## CONTENTS

Woven sieves.  
Tolerances for U. S. Standard sieves.

Pharmaceutical sieves.  
Bolting cloth.  
Sieves for sand, cement, pebbles, etc.  
Gages for broken stone, slag, etc.

## INTRODUCTION

The accuracy of woven metal sieves is often very high. An idea of the accuracy which may reasonably be expected in precision testing sieves may be obtained from the data in Table 2. For many purposes, such a narrow tolerance is not necessary and should not be required. An abnormally wide separation between two adjacent parallel wires may cause a serious error, especially in sieves with narrow openings. In bolting cloth, the diameters of the threads and the widths of the openings vary, not only from brand to brand, but even from bolt to bolt of the same brand. When accuracy is required, it is necessary to select particular portions of selected bolts of the cloth. Sieves are commonly designated either by the mesh per unit of length, or by the mesh per unit of area. Several different units of length (and of area) are employed. For U. S. A. grain sieves, see following publications of the U. S. Department of Agriculture: *Handbook of Official Grain Standards for Wheat, Shelled Corn, Oats, and Rye* (U. S. G. S. A. Form No. 90); *Handbook of United States Grades for Grain Sorghum* (U. S. G. S. A.-GI-Form No. 142); *United States Grades for Milled Rice* (Dept. Agriculture Circular 291); *Proposed Revision of United States Grades for Rough Rice* (Mimeograph U. S. G. S. A.-GI-No. 26).

## MATIÈRES

Tamis tissés.  
Tolérances pour les tamis standards des États Unis.

Tamis pharmaceutiques.  
Étamines.  
Tamis pour sable, ciment, cailloux, etc.  
Jauges pour pierres cassées, scories, etc.

## INTRODUCTION

La précision des tamis métalliques tissés est souvent très grande. On peut se faire une idée de la précision qui peut être raisonnablement attendue des tamis pour essais de précision, en consultant les données de la Table 2. Pour beaucoup de buts, une tolérance aussi étroite n'est pas nécessaire et ne doit pas être exigée. Une séparation anormalement large entre deux fils adjacents parallèles peut occasionner une sérieuse erreur spécialement dans les tamis à réseaux fins. Dans les étamines, les diamètres des fils et la largeur des ouvertures varient, non seulement de marques à marques, mais aussi souvent d'étamines à étamines de la même marque. Lorsqu'on exige de la précision, il est nécessaire de choisir des portions particulières d'étamines choisies. Les tamis sont communément désignés ou par le nombre de mailles par unité de longueur, ou par le nombre de mailles par unité de surface. On emploie plusieurs unités de longueur (et de surface) différentes. Pour les tamis de grains des États Unis, voir les publications suivantes du Département d'Agriculture des États Unis: *Handbook of Official Grain Standards for Wheat, Shelled Corn, Oats, and Rye* (U. S. G. S. A. Form No. 90) *Handbook of United States Grades for Grain Sorghum* (U. S. G. S. A.-Form No. 142); *United States Grades for Milled Rice* (Dept. Agriculture Circular 291) *Proposed Revision of United States Grades for Rough Rice* (Mimeograph U. S. G. S. A.-GI-No. 26).

## INHALTSVERZEICHNIS

Gewebte Siebe.  
Tolerierung für die Standard Siebe der Vereinigten Staaten.

Pharmazeutische Siebe.  
Siebtücher.  
Siebe für Sand, Zement, Kiesel, etc.  
Abmessung für Bruchsteine, Schlag, etc.

## EINLEITUNG

Gewebte Metallsiebe haben häufig einen hohen Grad von Genauigkeit. Eine Vorstellung davon, wie weit sich diese bei der Präzision der Prüfung treiben lässt, erhält man aus den Angaben der Tafel 2. Für viele Zwecke ist eine so kleine Toleranz nicht notwendig und soll auch nicht gefordert werden. Eine abnormal grosse Entfernung zwischen zwei benachbarten parallelen Drähten, kann Ursache grösserer Fehler werden, besonders bei Sieben mit engen Öffnungen. Bei Siebtüchern ändert sich der Durchmesser der Fäden und die Öffnungsweite nicht nur von Marke zu Marke, sondern sogar in den Tüchern derselben Marke. Ist hier Genauigkeit gefordert, so ist es notwendig, gewisse Teile der gewählten Tücher auszusondern. Siebe sind im allgemeinen entweder durch die Zahl der Maschen pro Längen- oder pro Flächeneinheit gekennzeichnet. Es sind einige verschiedene Längen- und Flächenmasse üblich. Für die Siebe (Korn, etc.) der Vereinigten Staaten siehe die folgenden Abhandlungen des U. S. Department of Agriculture: *Handbook of Official Grain Standards for Wheat, Shelled Corn, Oats, and Rye* (U. S. G. S. A. Form No. 90) (Korn Standard); *Handbook of United States Grades for Grain Sorghum* (U. S. G. S. A.-GI-No. 142) (Sandzucker); *United States Grades for Milled Rice* (Dept. Agriculture Circular 291) (Mühlen Reis); *Proposed Revision of United States Grades for Rough Rice* (Mimeograph U. S. G. S. A.-GI-No. 26).

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## INTRODUZIONE

Gli stacci di tessuto metallico hanno spesso un alto grado di esattezza. Una idea della approssimazione che può ragionevolmente attendersi con stacci per saggi di precisione, può dedursi dai dati della Tabella 2. Per molti scopi una tolleranza così stretta non è necessaria, e non potrebbe pretendersi. Una distanza anormalmente grande fra due fili paralleli adiacenti può essere causa di gravi errori, specialmente negli stacci a fori piccoli. Nelle tele da buratti, il diametro dei fili e l'ampiezza dei fori variano non solo da marca a marca, ma anche nei tessuti di una stessa marca. Se si richiede grande esattezza è necessario scegliere particolari porzioni di tessuti scelti. Gli stacci sono in genere designati in base al numero di maglie per unità di lunghezza o di superficie. Le unità adoperate sono differenti.

Per gli stacci da granaglie degli S. U. A. vedi le pubblicazioni seguenti del U. S. Department of Agriculture: *Handbook of Official Grain Standards for Wheat, Shelled Corn, Oats, and Rye* (U. S. G. S. A. Form No. 90); *Handbook of United States Grades for Grain Sorghum* (U. S. G. S. A.-GI-Form No. 142); *United States Grades for Milled Rice* (Dept. Agriculture Circular 291); *Proposed Revision of United States Grades for Rough Rice* (Mimeograph U. S. G. S. A.-GI-No. 26).

TABLE 1.—SERIES OF WOVEN SIEVES  
For pharmaceutical sieves, *see* Table 3

$D$  = diameter of wire (mm);  $O$  = width of opening (mm).

Sieve designation <sup>a</sup>	United States of America					Great Britain	France		Switzerland
	U. S. Standard <sup>b</sup>	Tyler <sup>c, d</sup> Standard screen scale	Howard <sup>d, e</sup> and Morse sieve series (old)	Newark <sup>d, e</sup> "Market Grade" test- ing sieves	Institute <sup>f, g</sup> Mining and Metallurgy; Standard screens	Suter- Strehler <sup>g</sup> sieve series	Weiller and Cie.	Franck and Cie.	Market <sup>h</sup> Grade test- ing sieve cloth
$N$	$D$	$O$	$O$	$O$	$O$	$O$	$O$		$O$
			*26.67 22.43 *18.85 15.85 *13.33 11.20 * 9.423						12
2			7.925				12.1		9.5
2½			* 6.680				9.5		7.8
3			5.613				8.1		
3½			* 4.699	5.11			5.94		5.8
4	1.27	4.76	3.962				4.66		4.5
5	1.12	4.00	* 3.327	3.33		2.540	3.83		3.7
6	1.02	3.36	2.794				3.27		3.2
7	0.92	2.83	* 2.362	2.43		1.574	2.77		2.7
8	0.84	2.38	1.981						2.4
9			* 1.651	1.86		1.270	2.18		2.1
10	0.76	2.00	1.397	1.49			1.81		1.9
11			* 1.168	1.23		1.056	1.54		1.75
12	0.69	1.68	0.991	1.07			1.34		1.45
14	0.61	1.41		0.93		0.792	1.14		1.35
15			* 0.833	0.85	0.864	0.635	1.03		1.30
16	0.54	1.19	0.701	0.71					1.10
18	0.48	1.00							0.95
20	0.42	0.84							0.87
22½									
24									
25	0.37	0.71					0.75		0.76
27½			* 0.589						0.66
28			0.495						
30	0.33	0.59	* 0.417	0.44	0.516	0.421	0.65		0.62
32			0.351	0.38		0.317	0.55		
35	0.29	0.50	* 0.295				0.494		0.53
40	0.25	0.42			0.381				0.47
42									
45	0.22	0.35							
48									
50	0.188	0.297		0.28	0.279	0.254	0.376		
60	0.162	0.250		0.23	0.234	0.211	0.30		
65			* 0.208						
70	0.140	0.210		0.20	0.185	0.180	0.26		
80	0.119	0.177		0.174	0.173	0.157	0.227		
90				0.155	0.155	0.139	0.209		
100	0.102	0.149	* 0.147	0.142	0.140	0.127	0.178		
110				0.127	0.130				
115			0.124						
120	0.086	0.125		0.117	0.117	0.107	0.151		
130				0.104	0.109		0.134		
140	0.074	0.105		0.100	0.107		0.128		
150			* 0.104	0.091	0.104	0.084	0.125		
160				0.088	0.097				
170	0.063	0.088	0.088	0.083	0.089		0.094		
180				0.079	0.084				
190				0.079	0.079				
200	0.053	0.074	* 0.074	0.071	0.074	0.063	0.089		
230	0.046	0.062			0.065				
250			0.061		0.061				
270	0.041	0.053	0.053		0.053				
300					0.046				
325	0.036	0.044	0.043		0.043				

<sup>a</sup> Sieve designation is number of meshes per linear unit. For U. S. and Great Britain the unit is the inch (=25.4 mm), excepting for the U. S. Standard, for which the unit varies slightly but always approximates closely to the inch; for the Suter-Strehler series it is 27.8 mm; and for Switzerland it is 27 mm.

<sup>b</sup> Specifications require a frame 8 in. in diameter (3 in. for paint pigments), and either 5 cm or 2.5 cm high (above cloth). For tolerances, *see* Table 2. This series has been tentatively adopted, as standard, by the American Society for Testing Materials, using a preferred designation of width of opening in microns. Sieves of this series now used by most A. S. T. M. committees, and specifications requiring other series, are in process of revision.

<sup>c</sup> Widths of openings in successive sieves are related as 1 to  $\sqrt{2}$  (=1.189); those starred (\*), as 1 to  $\sqrt{2}$  (=1.414). The scale is based upon the No. 200 sieve with openings 0.0029 in. wide. Successive sieves finer than No. 4 nominally correspond, within limits of tolerance, with successive sieves of the U. S. Standard series, but there are notable differences in the designations of the two series.

<sup>d</sup>  $D + O = 25.4/N$ .

<sup>e</sup> U. S. Standard is now regular with Howard and Morse, Inc., but the Old Howard and Morse Standard is obtainable.

<sup>f</sup> This series is the standard of British Engineering Standards Committee.

<sup>g</sup>  $D + O = 27.8/N$ .

<sup>h</sup>  $D + O = 27/N$ .

Designated by number of meshes per 27.777 mm; *cf.* preceding column. Sieves of the same designation are woven with wires of various sizes, and  $O$  varies accordingly: for example, the catalogue lists No. 20 sieve in 14 different sizes of wire.

Designated by number of meshes per 27 mm; for approximate size of openings, *see* following column.



TABLE 2.—TOLERANCES FOR U. S. STANDARD SIEVES\*

$D$  = diameter of wire;  $O$  = width of opening; min. = minimum; max. = maximum; av. = average. Unit: 1% of specified value.

Sieves	$O$		$D_{av.}$	
	Av.	Max.	Min.	Max.
4 to 18	$\pm 3$	10	-15	+30
20 to 45	$\pm 5$	25	-15	+30
50 to 120	$\pm 6$	40	-15	+35

TABLE 2.—TOLERANCES FOR U. S. STANDARD SIEVES.\*—(Continued)

$D$  = diameter of wire;  $O$  = width of opening; min. = minimum; max. = maximum; av. = average. Unit: 1% of specified value.

Sieves	$O$		$D_{av.}$	
	Av.	Max.	Min.	Max.
140 to 200	$\pm 8$	60	-15	+35
230 to 325	$\pm 8$	90	-15	+35

\* See Table 1.

Example: For sieve No. 30 of U. S. Standard, the average diameter of the wire must be not more than 15 % smaller or 30 % greater than 0.33 mm (Table 1); the width of the average opening must not differ from 0.59 mm by more than  $\pm 5$  % ( $= \pm 0.01$  mm), and the width of the largest opening must not exceed 0.59 mm by more than 25 % ( $= 0.15$  mm).

TABLE 3.—PHARMACEUTICAL SIEVES

In the body of the table are indicated the sieves composing a complete set, and the customary designations of the several sieves: \* indicates that the sieve is designated by the number of meshes per cm as given in first column (Italy is an exception: see note). "Width" = width of opening.

Meshes per cm	Width (mm)	Austria	Belgium	Denmark	Finland	France		Germany	Great Britain	Hungary	Italy <sup>2</sup>	Japan	Mexico	Netherlands <sup>3, 4</sup>	Norway	Russia	Sweden <sup>6</sup>	Switzerland <sup>3</sup>	U. S. A.
						Old <sup>1</sup>	New												
	8	I								I					1				
2	6		*	*		5	I												
3	5				I	8	II			II		1	1		2				
	4		*	*								2	2						
	3	II			II					III		3	3		3				
	2	III	*	*	III														
5						16	III												
6	1.5					25	IV			IV	*	4	4	*	4	IV	No. 10		
9						40	V	4										IV	
10	0.75	IV	*	*	IV														
15						60	VI			V		5							
18			*			70	VII												
20						80	VIII				*		5	*	6	II	No. 30		
22																			
25						100	IX	5		VI	*	6		*	7	I	No. 40		
26		V				120	X						6	*					
27																			
30			*	*		140	XI	6											
32	0.30				V														
37																			
40			*																
45																			
48		} VI											6	*					
50				* <sup>6</sup>															
51																			
52																			
70	0.15				VI								7						
Grading <sup>5</sup>		<i>a</i>	<i>b</i>	<i>c</i>	<i>a</i>	<i>d</i>	<i>d</i>	<i>e</i>	<i>h</i>	<i>a</i>	<i>a</i>	<i>c</i>	<i>d</i>		<i>d</i>	<i>f</i>	<i>g</i>	<i>d</i>	<i>i</i>

<sup>1</sup> Numbers in this column are the number of meshes per "pouce" (=2.7 cm), and are the customary commercial designations of the sieves.

<sup>2</sup> Sieves designated by number of openings per cm<sup>2</sup> = square of number of meshes per cm.

<sup>3</sup> Also sieves with round holes; diameters, 1.5 mm, 3 mm, and 5 mm.

<sup>4</sup> Manufacturers commonly designate sieves by meshes per 26 mm.

<sup>5</sup> Material which passes a sieve of 9 or 10 meshes per cm is considered a "powder," and powders are graded, depending upon the country, in accordance with one of the following systems:

(a) Coarse, fine, very fine; (b) "farines," medium fine, fine, very fine; (c) coarse, medium, fine; (d) coarse, medium fine, fine, very fine; (e) coarse, medium fine, fine; (f) coarse, medium, fine, very fine; (g) coarse, medium coarse, medium fine, fine; (h) 20 to 30 mesh = coarse powder, 40 to 60 = powder, 80 to 120 = fine powder; (i) No. 12 = very coarse, No. 20 = coarse, No. 40 = moderately coarse, No. 50 = moderately fine; No. 60 = fine, No. 80 = very fine; No. 6, No. 30, and No. 100 also used.

<sup>6</sup> Silk sieves.

Selected from U. S. Standard. Table 1

TABLE 4.—BOLTING CLOTH

Designation	Switzerland,* mesh per linear inch (=25.4 mm)		France
	Bodmer	Wydler	
No.			Designated by number of meshes per pouce (=27 mm)
0000	18	18	
000	23	23	
00	28	29	
0	38	38	
1	48	48	
2	54	54	
3	58	58	
4	62	62	
5	66	66	
6	74	74	
7	82	82	
8	86	86	
9	97	97	
10	109	109	
11	116	116	

TABLE 4.—BOLTING CLOTH.—(Continued)

Designation	Switzerland,* mesh per linear inch (=25.4 mm)		France
	Bodmer	Wydler	
12	124	125	Designated by number of meshes per pouce (=27 mm)
13	130	129	
14	139	140	
15	148	149	
16	157	157	
17	165	163	
18	170	166	
19	175	169	
20	180	175	
21	185	185	
25	200	197	

\* The "quality" of the cloth is determined by the coarseness of the thread used. The figures given apply to the Standard, the Extra (X), and the Double Extra (XX) qualities. For the Triple Extra Heavy (XXX) quality the number of meshes per inch is in each case one less than the number given in the table. Diameter of threads is not specified. *Grit gauze* is designated by number of meshes per inch (= 25.4 mm) and is obtainable from No. 14 to No. 86.

TABLE 5.—WOVEN SIEVES FOR SPECIAL PURPOSES (METRIC DESIGNATION)

Sand and cement sieves, except as indicated for pharmaceutical sieves, *see* Table 3

In the body of the table are given the widths of the openings (*O*) in mm. If *D* = diameter of wire (mm) and *N* = number of meshes per cm,  $D = 10/N - O$ . Sieves are woven, except as noted. \* indicates that neither *D* nor *O* is specified.

Mesher per cm <sup>2</sup> .....	64	144	225	324	900	2500	4900	5000	6400	
Mesher per cm = <i>N</i> =.....	8	12	15	18	30	50	70	70.71	80	
			Millimeters							
Austria.....	0.85	0.53			0.23		0.09			a
Argentina.....					0.18		0.09			
Belgium.....	0.85	0.53			0.18					
Brazil.....					*					
China.....			British sieves used to some extent. <i>See</i> Table 6							
Denmark.....					0.222	0.13		0.09		b, c
Finland.....					*		*			
France.....				0.36	0.18		0.09			d
Germany.....					0.222					b, e
Germany (for coal dust, etc.) <sup>k</sup> .....	Designation is <i>N</i> ; <i>O</i> = 6/ <i>N</i> ; <i>D</i> = 4/ <i>N</i>									
Great Britain.....	<i>See</i> Table 6									
Hungary.....	0.85	0.53			0.23		0.09			
Italy.....					0.18		0.09			
Japan.....	0.85	0.53	0.47		0.23					
Mexico.....	<i>See</i> Table 6									
Netherlands.....					0.23		0.09			f
Norway.....					0.23			0.09		
Portugal.....					*			*		g
Rumania.....					*		*			
Russia.....	0.85	0.53	0.47		0.23		0.09			h
Spain.....				0.36	0.18		0.09			
Sweden.....					0.222					b, i
Switzerland.....	0.85	0.53			0.23		0.09			j
United States of America.....	<i>See</i> Table 6									
Uruguay.....					*		*			

<sup>a</sup> Also copper plates with round holes 1.5 mm and 1.0 mm in diameter.  
<sup>b</sup> Also, for cement sand, plate 0.25 mm thick with round holes 1.350 mm and 0.775 mm in diameter.  
<sup>c</sup> For sand and pebbles, plates with round holes 60, 30, 15, 10, 5, 2, and 0.5 mm in diameter.  
<sup>d</sup> Also plates with round holes 2, 1.5, 1, and 0.5 mm in diameter. For other woven sieves *see* Table 1.  
<sup>e</sup> Commercial designations recognized: meshes per inch (25.4 mm), meshes per old French inch (=pouce = 27 mm), meshes per Rhenish in. (= Zoll = 26.15 mm) and meshes per cm, as well as meshes per cm<sup>2</sup>.  
<sup>f</sup> Sieves commonly designated by meshes per inch of 26 mm.  
<sup>g</sup> French sieves are used in flour industry; British sieves, in mining industry.  
<sup>h</sup> Sieves in common use are designated by meshes per linear inch, meshes per linear verchoc (44.45 mm), and meshes per cm<sup>2</sup>.  
<sup>i</sup> Tidbeck sieves are designated by meshes per inch of 25 mm.  
<sup>j</sup> For other woven sieves, *see* Tables 1, 3, 4. For *Grit Gauze* *see* Table 4, footnote.  
<sup>k</sup> Tolerance in mean value of *O* = ±5 %; max. deviation for *N* = 1 to 7 is ±10 %, 8 to 20 is ±20 %; 20 to 100 is ±30 %. Tolerance in mean value of *D* for *N* = 1 to 4 is ±3 %, 5 to 70 is ±4 %, 80 to 100 is ±5 %; max. deviation for same limits of *N* are ±6 %, ±8 %, ±10 %, respectively. Series consists of *N* = 1, 2, 3, 4, 5, 6, 8, 10, 11, 12, 14, 16, 20, 24, 30, 40, 50, 60, 70, 80, 100.



TABLE 6.—WOVEN WIRE SIEVES FOR SPECIAL PURPOSES\* (INCH DESIGNATION)

American and British; for pharmaceutical sieves, see Table 3

$D$  = diameter of wire;  $\delta D$  = amount by which the average  $D$  of all the wires in one direction may depart ( $\pm$ ) from value specified for  $D$ ;  $\delta n$  = allowable variation ( $\pm$ ) in  $n$  per whole cm; max. [min.] = maximum [minimum] allowable value;  $N$  = approximate number of meshes per in.;  $n$  = number of meshes per cm;  $O$  = width of opening;  $S$  = specified value.

Sieve designation†	Unit of $O$ , $D$ , $\delta D = 1$ mm															Sieve designation	Unit of $O$ , $D = 1$ mm			
	Cement and sand										Sand and fine highway material (cement concrete excepted). U. S. A.‡						Aggreg.††	U. S.	Stone** G. B.	
	U. S.§§	Canada§	Mexico§	Great Britain††																
				$O$	$O$	$O$	$O$		$n$		$D$ §			$O$	$n$					$\delta n$
$N$				$S$	Max.	Min.	Max.	$S$	Min.	Max.										
10											2.00	3.9	0.04	0.56	0.05	3	76.0	6.3		
20	0.85	0.85		0.85	1.02	7.5	8.3	0.42	0.41	0.43	0.85	8	0.2	0.40	0.015	2	50.8	4.88		
30	0.57	0.57		0.57	0.69	11.4	12.2	0.27	0.27	0.28	0.50	12	0.4	0.33	0.012	1½	38.0	4.50		
40											0.36	16	0.6	0.26	0.010	1	25.4	4.12	3.7	
50											0.29	20	0.8	0.21	0.010	¾	19.0	3.42	3.7	
76				0.224	0.28	29.1	30.7	0.112	0.107	0.117						½	12.7		3.0	
80											0.17	31	1	0.15	0.008	⅜	9.5	2.33	2.6	
100	0.14		0.14								0.14	39	1	0.116	0.008	¼	6.4		2.3	
180				0.097	0.127	69.3	72.4	0.046	0.041	0.051						⅓	3.2		1.8	
200	0.074	0.074	0.066								0.074	79	3	0.053	0.005	⅙	1.6		1.4	

\* Sieves selected from the series given in Table 1 are not separately considered here.

† Designation is meshes per inch, or meshes per inch<sup>2</sup> in the form "10 × 10," etc.‡ Sieves specified by American Society for Testing Materials; also wire sieves of 400 meshes per cm<sup>2</sup> are specified for certain chemical analyses of metals; for coke, sieves with openings, 2.5, 1.75, 1.25, 0.75, and 0.5 in. wide are used. See also Table 1.§  $D + O = 25.4/N$ .

|| Designation is width of opening in inches; British use the form 3 × 3, etc.

¶ Concrete aggregates. Tolerance: average opening,  $\pm 3\%$ ; max.  $O$ ,  $\pm 10\%$ ;  $D$ ,  $\pm 10\%$ .

\*\* Stone chippings. For broken stone, see Table 7.

†† British Engineering Standards Committee's sieves. Frames 203.20 mm square, at least 69.85 mm deep; cloth woven (not twilled).

TABLE 7.—GAGES FOR BROKEN STONE AND SLAG, ETC.

American and British

U. S. A.*						Great Britain†	
Diameter		Diameter		Diameter		Size of stone	Diameter of hole
in.	mm	in.	mm	in.	mm		mm
4	101.6	2	50.8	0.75	19.0	3-in.	76.2
3.5	88.9	1.5	38.1	0.5	12.7	2.5-in.	63.5
3	76.2	1.25	31.8	0.25	6.4	2-in.	50.8
2.5	63.5	1	25.4			1.5-in.	38.1

\* Round holes, specified by their diameters in inches. For sizing gypsum rings 76, 38, and 25 mm in diameter are used.

† Gages are of sheet metal at least 5 mm thick and contain both circular holes and slots.

# SACCHARIMETRY, THE PROPERTIES OF COMMERCIAL SUGARS AND THEIR SOLUTIONS

FREDERICK BATES, F. P. PHELPS, C. F. SNYDER

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$C_{12}H_{22}O_{11}$ , maltose.....	$C_6H_{12}O_6$ , invert sugar....	$C_5H_{10}O_5$ , arabinose.....		
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## INTRODUCTION

### Saccharimetric Methods and Standards

**Specific Rotation.**—The specific rotation  $[\alpha]$  of any substance in the dissolved state is represented and defined by the equation

$$[\alpha]_X^{t^\circ} = \frac{\alpha}{lC} = \frac{\alpha}{lpd}$$

where  $t$  designates the temperature of measurement,  $X$  is a character used to identify the wave length of the light source used,  $\alpha$  is the observed rotation in circ. deg.,  $l$  the length of the solution in dm,  $C$  its concentration in g per ml at  $t^\circ$ ,  $p$  its concentration in wt. %, and  $d$  its density in g/ml at  $t^\circ$ .  $[\alpha]$  varies with  $X$ , and to a less extent with  $t$  and  $C$  (or  $p$ ). Wherever possible the values of the specific rotations of the more important sugars are given at

definite intervals of concentration.  $[\alpha]$  for all intermediate concentrations may be found by interpolation.

**Saccharimetric Method.**—Since monochromatic light sources are difficult to obtain, it is frequently more convenient to use a white-light source and a quartz-wedge saccharimeter. This saccharimeter is particularly applicable to the sugar group because the rotatory dispersions of quartz and the common sugars are very similar. The conditions for accurate observing are improved if the violet end of the spectrum is absorbed by the potassium bichromate cell. The saccharimetric scale is defined by the rotation of sucrose, its hundred point being the rotation of 26 g (in air,  $d = 0.0012$ , brass weights) in 100 ml of solution. Therefore in order to determine a sugar having a different rotatory power, the weight used must be adjusted to the sucrose scale, i.e., the sac-



saccharimetric normal weight of the sugar in question is that weight which, dissolved in 100 ml of solution, will give a rotation of  $100^\circ$  on the sucrose scale. To compute this weight use, whenever the data are available, the results of direct determinations of the values of the rotations on the sucrose scale.

In the case of the first four sugars of the following table, determinations have been made of the relation between the rotation in sucrose deg. ( $^\circ S$ ) and circ. deg. of sodium light for the same solution. If this relation is known, the saccharimetric normal weight for the saccharimeter can be computed from the known specific rotation.

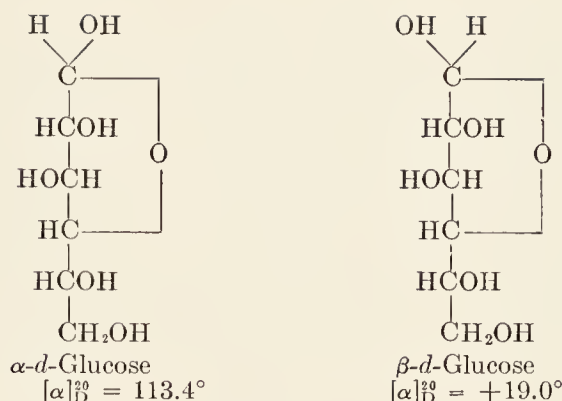
In the case of many sugars no direct determinations of the relative values of the sugar deg. and circ. deg. are available, and in these instances the saccharimetric normal weight must be computed from the relative specific rotations of sucrose and of the sugar in question on the assumption that the rotation dispersion of all the sugars is the same as that of sucrose, which is not strictly true. Saccharimetric normal weights so computed must therefore be considered only as the nearest approximation at present available. The computation depends upon the assumption that the saccharimetric normal weights of the sugars vary inversely as their specific rotations.

SACCHARIMETRIC NORMAL WEIGHTS,  $W_N$ In air,  $d = 0.0012$ , brass weights

Sugar	$1^\circ S =$	$W_N$
Dextrose.....	0.3448	32.248
Lactose.....	.3452	32.857
Maltose.....	.3449	12.474
Raffinose (5H <sub>2</sub> O).....	.3450	16.507
Levulose.....	calc.	18.592
Invert sugar.....	calc.	86.450

Thus in the determination of these sugars it is merely necessary to weigh out the appropriate normal weight of the sugar and proceed exactly as in the analysis of sucrose. The specific rotation is in general not exactly proportional to the concentration of the sugar, and for accurate work a correction should be applied for readings which vary much from the  $100^\circ$  point. Many experimenters advise using a variable saccharimetric normal weight according to the concentration of the sugar taken, but this requires a previous knowledge of the quantity of sugar present or a preliminary assay of the material. It is more convenient to use a uniform saccharimetric normal weight and to apply a correction for the various parts of the sugar scale.

**Mutarotation.**—In a very large class of sugars a considerable lapse of time is required for the dissolved sugar to exhibit a stable rotatory power. The rotation of the freshly prepared solution in general steadily changes according to the laws of unimolecular reactions, to a steady state, where no further change occurs. This phenomenon is called "mutarotation." The specific rotation of the sugar is commonly expressed in terms of this equilibrium condition. Mutarotation has been satisfactorily explained by the discovery of two modifications of each of the sugars in which the phenomenon exists. These two modifications have been designated the  $\alpha$ - and  $\beta$ -forms. When the sugar crystallizes, but one of these forms separates from solution, usually on account of a considerable difference in solubility, and, consequently, when a fresh solution is prepared the rotatory power of this form is exhibited. The most plausible explanation of the isomerism of the  $\alpha$ - and  $\beta$ -forms is connected with the end carbon atom which is capable of changing its relation to the rest of the molecule. For example, in the case of dextrose the mutarotation reaction is regarded as a balanced reaction between the two forms:—



The steady state is, under this hypothesis, a state in which the reaction velocities  $\alpha \rightarrow \beta$  and  $\beta \rightarrow \alpha$  are equal.

As the change of one form into the other obeys the laws of mass action and appears to be a unimolecular reaction, the mutarotation constant is expressed by the formula

$$k_1 + k_2 = \frac{1}{t} \log_{10} \frac{r_0 - r_\infty}{r_t - r_\infty},$$

$r_0$  and  $r_\infty$  being the initial and final rotations, and  $r_t$  the rotation at the time,  $t$ , from the start.

**International Sugar Scale.**—The Ventzke sugar scale, although in general use for many years, has never been fully understood by polariscopists generally. This has led to much confusion and to the use of 100 ml flasks on instruments standardized for use with the Mohr flask. In addition,  $17.5^\circ C$  is well below the temperature of the average laboratory. Because of these and other considerations the International Sugar Commission at the Paris meeting in 1900 recommended the use of a new definition of the  $100^\circ$  point based upon true ml and a standard temperature of  $20^\circ C$ . In order to divorce it as completely as possible from confusion with the Ventzke scale, the new scale is referred to as the international sugar scale because of its origin. The change to  $20^\circ C$  necessitated a change in the saccharimetric normal weight in order to keep the new scale comparable with the Ventzke. Correcting for the change in the specific rotation ( $-0.000184$ ), the expansion of a glass tube ( $+0.000008$ ), quartz wedge ( $-0.000130$ ), and metal scale ( $-0.000018$ ), the new weight becomes  $26.000 + g$ . The *international sugar scale* was then defined at the Paris meeting as follows: The graduation of the saccharimeter and all readings shall be made at  $20^\circ C$ ; 26 g (in air,  $d = 0.0012$ , brass weights) of sucrose are dissolved in water and the volume made up to 100 ml at  $20^\circ C$ . This will determine the  $100^\circ$  point.

**Standardization of International Sugar Scale.**—The  $100^\circ S$  point on the international sugar scale was determined by Herzfeld and Schönrock in 1900–1904 (33, 82), with the result that  $100^\circ S = 34.657^\circ$  ( $\lambda = 589.25 m\mu$ ). In 1916 Bates and Jackson (9) of the Bureau of Standards, as the result of an elaborate investigation, found that  $100^\circ S = 34.620$  ( $\lambda = 589.25 m\mu$ ). They found that the saccharimetric normal sucrose solution as defined by the International Sugar Commission did not read  $100^\circ S$  on saccharimeters standardized on the Herzfeld-Schönrock basis. Subsequently additional investigations were carried out at the Institut für Zucker-Industrie (52) and at the Research Institute for the Czechoslovakian Sugar Industry (87). The readings of the saccharimetric normal sucrose solution on the original Herzfeld-Schönrock scale are given in the following table:

Original Herzfeld-Schönrock determination....	1900–1904	100.00 $^\circ S$ (33, 82)
Bates and Jackson.....	1916	99.895 (99.870–99.91) (9)
Stanek.....	1921	(99.81–99.90) (87)
Kraisly and Traegel.....	1924	99.834 (99.775–99.895) (52)



**Saccharimetric Scale Conversion Factors.**—Comparisons may be made between the readings of different scales by means of the following conversion factors: 1° International sugar scale = 0.34620° angular rotation  $D$ ; 1° French sugar scale = 0.21666° angular rotation  $D$ ; 1° Wild sugar scale = 0.13284° angular rotation  $D$ . (Saccharimetric normal weight = 26.00 g International scale = 16.29 g French scale = 10.00 g Wild scale.)

**Quartz Control Plates.**—The accuracy of the readings on the quartz wedge saccharimeter is checked by means of quartz control plates accurately standardized for the mercury line,  $\lambda = 546.1\text{m}\mu$ . In order to obtain a quartz rotation for  $\lambda = 589.25$ , use the equation

$$\frac{\phi_{\lambda=589.25}}{\phi_{\lambda=546.1}} = 0.85085 \quad (6, 9)$$

where  $\phi$  is the rotation in circ. deg. By this method the errors due to the character of the sodium source of light are eliminated and the measurements of one observer may be readily compared with those of another. The rotation of quartz in circ. deg. at a temperature  $t$  is given by:

$$\phi_t = \phi_0 (1 + 0.000144t), \text{ between } 4 \text{ and } 50^\circ\text{C}$$

#### THICKNESS OF THE NORMAL QUARTZ PLATE (9)

Wave length of light source, Å	Rotation of normal plate (Bates and Jackson)	Rotation of 1 mm of quartz at 20°C; light parallel to optic axis	Thickness of normal plate, mm
5892.5	34.620°	21.7182° (Gumlich)	1.5940
5892.5	34.620°	21.7283° (Lowry)	1.5934
5461	46.690°	25.5371° (Lowry)	1.5934

**Rotation of Normal Quartz Plate (9).** Normal quartz plate = 100°S = 34.620° ( $\lambda = 5892.5 \text{ Å}$ ) at 20°C; 1° ( $\lambda = 5892.5 \text{ Å}$ ) = 2.8885°S. Normal quartz plate = 100°S = 40.690° ( $\lambda = 5461 \text{ Å}$ ) at 20°C; 1° ( $\lambda = 5461 \text{ Å}$ ) = 2.4576°S.

**Absolute Rotation of Saccharimetric Normal Sucrose Solutions (9).**—The rotation of the saccharimetric normal sucrose solution for  $\lambda = 5461 \text{ Å}$  by direct measurement is: 100° sucrose = 40.763° of arc. Since the rotation ratio for the saccharimetric normal solution for  $\lambda = 5892.5 \text{ Å}$  and  $\lambda = 5461 \text{ Å}$  is 0.84922° the rotation of the saccharimetric normal solution for  $\lambda = 5892.5 \text{ Å}$  is 34.617°.

**Rotation Ratios for Quartz and for Sucrose Solutions (9).**—The ratios of the rotations in circ. deg. of quartz and of sucrose solutions for two wave lengths are as follows: For quartz  $\frac{\phi_{\lambda=5892.5\text{Å}}^{20}}{\phi_{\lambda=5461\text{Å}}^{20}} =$

$$0.85085 \text{ and for sucrose } \frac{\phi_{\lambda=5892.5\text{Å}}^{20}}{\phi_{\lambda=5461\text{Å}}^{20}} = 0.84922.$$

**Rotatory Dispersion Curves of Quartz and of Sucrose Solution (9).**—The difference between the rotations of the normal quartz plate and the saccharimetric normal sucrose solution for  $\lambda = 589.25\text{m}\mu$  is 0.003° and for  $\lambda = 546.1\text{m}\mu$ , 0.073°. The values indicate that the rotatory dispersion curves of plate and solution cross at about  $\lambda = 585\text{m}\mu$ . The reading of the saccharimetric normal solution on the true saccharimeter scale with the source  $\lambda = 589.25\text{m}\mu$  has been calculated to be 99.99°S.

**Rotation Difference, in Sucrose Degrees, for Saccharimetric Normal Sucrose Solution between  $\lambda = 5461 \text{ Å}$  and  $\lambda = 5892.5 \text{ Å}$ .**—Saccharimeter reading ( $\lambda = 5461 \text{ Å}$ ) — saccharimeter reading ( $\lambda = 5892.5 \text{ Å}$ ) = 0.192°S (9).

#### C<sub>12</sub>H<sub>22</sub>O<sub>11</sub>, SUCROSE

(Composition: Levulose < > Dextrose)

#### Optical Rotation

##### IN H<sub>2</sub>O

( $p$  = wt. % sucrose;  $C$  = g sucrose per 100 ml solution).  
 $[\alpha]_D^{20} = 66.386^\circ + 0.015035p - 0.0003986p^2$  [Tollens (88)].  
 $[\alpha]_D^{20} = 66.438^\circ + 0.010312p - 0.0003545p^2$  [Nasini and Villa-

vecchia (67)]. Landolt (55) has combined the above giving.  
 $[\alpha]_D^{20} = 66.435^\circ + 0.00870C - 0.00023C^2$ , ( $C$  from 0 to 65) or,  
 $[\alpha]_D^{20} = 66.412^\circ + 0.012673p - 0.0003765p^2$  between  $p = 0$  and 50 wt. %; all weights in vacuo.

$\lambda$ , (m $\mu$ )	589.25 ( $D$ )		546.1		Based on weights in vacuo
$[\alpha]_\lambda^{20}$	66.53	66.50	78.34	78.29	
Lit.	(9)	(84)	(9)	(84)	

#### SPECIFIC ROTATION OF SUCROSE IN H<sub>2</sub>O FOR DIFFERENT WAVE LENGTHS

$\lambda$ , m $\mu$	$[\alpha]^{18}$ (70)	$\lambda$ , m $\mu$	$[\alpha]^{20}$ (59)
589	66.8	Hg, 546.1	78.16
500	99.8	Cu, 521.8	86.21
450	122.2	Cu, 515.3	88.68
400	149.9	Cu, 510.6	90.46
350	192.9	Cd, 508.6	91.16
300	297.7	Zn, 481.1	103.07
250	543.0	Cd, 480.0	103.62
$\lambda$ , m $\mu$		$[\alpha]^{22}$ (46)	$[\alpha]^{20}$ (59)
1300	11.93	Zn, 472.2	107.38
1200	14.21	Zn, 468.0	109.49
1100	17.02	Cd, 467.8	109.69
1000	20.76	Fe, 438.4	126.5
900	26.32	Fe, 437.6	127.2
800	33.93	Hg, 435.8	128.49
700	44.68	Fe, 435.3	128.5
600	62.48	Fe, 433.7	129.8
$\lambda$ , m $\mu$		$[\alpha]^{20}$ (59)	
Li, 670.8	50.51	Fe, 431.5	130.7
Cd, 643.8	55.04	Fe, 428.2	133.6
Zn, 636.2	56.51	Fe, 427.2	134.2
Na, 589.3	66.45	Fe, 426.1	134.9
Cu, 578.2	69.10	Fe, 419.1	140.0
Hg, 578.0	69.22	Fe, 414.4	144.2
Cu, 570.0	71.24	Fe, 388.9	166.7
		Fe, 383.3	171.8
		Fe, 382.6	173.1

#### VALUES OF $[\alpha]_\lambda^{20}$ FOR SUCROSE IN WATER AND IN PYRIDINE (30) $C$ = moles sucrose per liter of solution

$\lambda$ , (m $\mu$ )	$C$			Pyridine		
	Water	Water	Water	Pyridine	Pyridine	Pyridine
	$\frac{1}{8}$	$\frac{1}{16}$	$\frac{1}{32}$	$\frac{1}{8}$	$\frac{1}{16}$	$\frac{1}{32}$
656	53.18	53.32	53.48	64.86	65.44	65.98
589	66.5	66.71	66.81	84.37	85.10	85.89
535	82.25	82.76	82.93	99.22	100.87	101.86
508	91.53	91.79	92.59	114.37	116.15	118.01
479	104.24	104.67	105.42	133.67	135.5	137.23
447	121.63	122.80	123.80	152.25	154.38	156.57

#### SUCROSE IN PYRIDINE (96)

% S.....	0		1		2		4		6.25	
$d_4^{25}$ .....	0.9735		0.9805		0.9829		0.9912		1.0010	
$[\alpha]_D^{25}$ .....			86.7		85.9		84.7		83.6	

$t$ , °C.....	-10	0	+10	25	45	65	85	105
$d_4^t$ .....	1.034	1.0248	1.0510	1.0005	0.9811	0.9619	0.9420	0.9220
$[\alpha]_D^t$ .....	88.7	87.3	85.6	83.8	82.0	80.3	78.5	77.0

#### EFFECT OF SALTS ON THE ROTATION OF SUCROSE IN H<sub>2</sub>O AT 20°C

The rotation in deg.  $S$  of a saccharimetric normal sucrose solution containing  $m$  grams of salt per 100 ml of solution is expressed by the equation  $R = 100 - am$ , where  $a$  has the following values:



Salt	NaCl	NH <sub>4</sub> Cl	K <sub>2</sub> C <sub>2</sub> O <sub>4</sub>	CaCl <sub>2</sub>	Pb (C <sub>2</sub> H <sub>3</sub> O <sub>2</sub> ) <sub>2</sub> ; v. Fig. 1
a	0.265	0.169	0.234	0.339	m 1.0 2.0 5.0
m <sub>max</sub>	3.7	6.8	4.0	3.3	R - 100 0.03 0.04 0.11

[α]<sub>D</sub><sup>25</sup> for a 9.60% sucrose solution containing NaCl is expressed by the equation [α]<sub>D</sub><sup>25</sup> = 66.410 - 1.456r for values of r up to 1.3; r = ratio, g NaCl to g sugar (91, 92, 93).

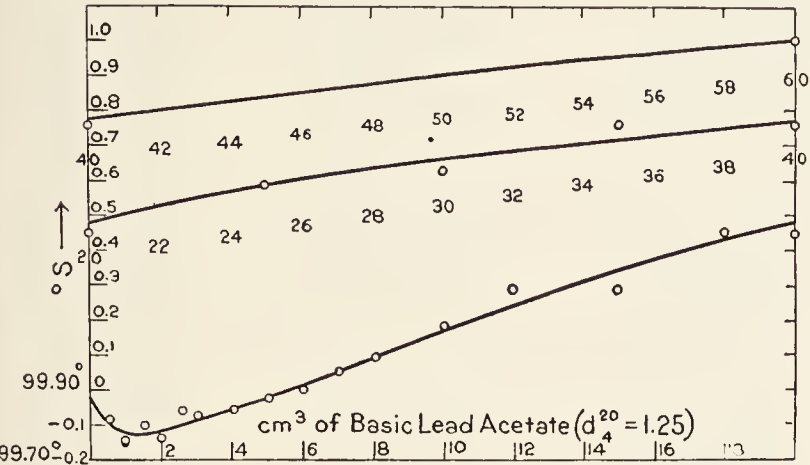


FIG. 1.

Refractive Index

REFRACTIVE INDEX OF AQUEOUS SUCROSE SOLUTIONS AT 20°C (83)  
Schönrock's table for determining water in sucrose solutions by means of the Abbe refractometer (83)

n <sub>D</sub> <sup>20</sup>	%H <sub>2</sub> O	n <sub>D</sub> <sup>20</sup>	%H <sub>2</sub> O	n <sub>D</sub> <sup>20</sup>	%H <sub>2</sub> O	n <sub>D</sub> <sup>20</sup>	%H <sub>2</sub> O
1.3330	100.0	1.3374	97.0	1.3418	94.0	1.3502	88.5
1.3331	99.9	1.3375	96.9	1.3419	93.9	1.3504	88.4
1.3333	99.8	1.3377	96.8	1.3421	93.8	1.3505	88.3
1.3334	99.7	1.3378	96.7	1.3423	93.7	1.3507	88.2
1.3336	99.6	1.3380	96.6	1.3424	93.6	1.3508	88.1
1.3337	99.5	1.3381	96.5	1.3425	93.5	1.3510	88.0
1.3338	99.4	1.3382	96.4	1.3427	93.4	1.3512	87.9
1.3340	99.3	1.3384	96.3	1.3429	93.3	1.3513	87.8
1.3341	99.2	1.3385	96.2	1.3430	93.2	1.3515	87.7
1.3342	99.1	1.3387	96.1	1.3431	93.1	1.3516	87.6
1.3344	99.0	1.3388	96.0	1.3433	93.0	1.3518	87.5
1.3345	98.9	1.3389	95.9	1.3435	92.9	1.3520	87.4
1.3347	98.8	1.3391	95.8	1.3436	92.8	1.3521	87.3
1.3348	98.7	1.3393	95.7	1.3437	92.7	1.3523	87.2
1.3350	98.6	1.3394	95.6	1.3439	92.6	1.3524	87.1
1.3351	98.5	1.3395	95.5	1.3441	92.5	1.3526	87.0
1.3353	98.4	1.3397	95.4	1.3442	92.4	1.3527	86.9
1.3355	98.3	1.3399	95.3	1.3443	92.3	1.3529	86.8
1.3356	98.2	1.3400	95.2	1.3445	92.2	1.3531	86.7
1.3357	98.1	1.3401	95.1	1.3447	92.1	1.3532	86.6
1.3359	98.0	1.3403	95.0	1.3448	92.0	1.3533	86.5
1.3361	97.9	1.3405	94.9	1.3450	91.9	1.3535	86.4
1.3362	97.8	1.3406	94.8	1.3451	91.8	1.3537	86.3
1.3363	97.7	1.3407	94.7	1.3453	91.7	1.3538	86.2
1.3365	97.6	1.3409	94.6	1.3454	91.6	1.3539	86.1
1.3367	97.5	1.3411	94.5	1.3456	91.5	1.3541	86.0
1.3368	97.4	1.3412	94.4	1.3458	91.4	1.3543	85.9
1.3369	97.3	1.3413	94.3	1.3459	91.3	1.3544	85.8
1.3371	97.2	1.3415	94.2	1.3461	91.2	1.3546	85.7
1.3373	97.1	1.3417	94.1	1.3462	91.1	1.3547	85.6
1.3549	85.5	1.3631	80.5	1.3723	75.0		
1.3551	85.4	1.3632	80.4	1.3725	74.9		
1.3552	85.3	1.3634	80.3	1.3726	74.8		
1.3554	85.2	1.3636	80.2	1.3728	74.7		
1.3555	85.1	1.3637	80.1	1.3730	74.6		
1.3557	85.0						
1.3559	84.9						
1.3560	84.8						
1.3562	84.7						
1.3563	84.6						
1.3565	84.5						
1.3567	84.4						
1.3568	84.3						
1.3570	84.2						
1.3571	84.1						
1.3573	84.0						
1.3575	83.9						
1.3576	83.8						
1.3578	83.7						
1.3580	83.6						
1.3582	83.5						
1.3583	83.4						
1.3585	83.3						
1.3587	83.2						
1.3588	83.1						
1.3590	83.0						
1.3592	82.9						
1.3593	82.8						
1.3595	82.7						
1.3596	82.6						
1.3598	82.5						
1.3600	82.4						
1.3601	82.3						
1.3603	82.2						
1.3604	82.1						
1.3606	82.0						
1.3608	81.9						
1.3609	81.8						
1.3611	81.7						
1.3612	81.6						
1.3614	81.5						
1.3616	81.4						
1.3617	81.3						
1.3619	81.2						
1.3620	81.1						
1.3622	81.0						
1.3624	80.9						
1.3625	80.8						
1.3627	80.7						
1.3629	80.6						
1.3631	80.5						
1.3632	80.4						
1.3634	80.3						
1.3636	80.2						
1.3637	80.1						

$n_D^{20}$	%H <sub>2</sub> O	$n_D^{20}$	%H <sub>2</sub> O	$n_D^{20}$	%H <sub>2</sub> O	$n_D^{20}$	%H <sub>2</sub> O	$n_D^{20}$	%H <sub>2</sub> O	$n_D^{20}$	%H <sub>2</sub> O
1.3731	74.5	1.3829	69.0	1.3929	63.5	1.4036	58.0	1.4147	52.5	1.4264	47.0
1.3733	74.4	1.3831	68.9	1.3931	63.4	1.4038	57.9	1.4150	52.4	1.4266	46.9
1.3735	74.3	1.3833	68.8	1.3933	63.3	1.4040	57.8	1.4152	52.3	1.4268	46.8
1.3737	74.2	1.3834	68.7	1.3935	63.2	1.4042	57.7	1.4154	52.2	1.4270	46.7
1.3738	74.1	1.3836	68.6	1.3937	63.1	1.4044	57.6	1.4156	52.1	1.4272	46.6
1.3740	74.0	1.3838	68.5	1.3939	63.0	1.4046	57.5	1.4158	52.0	1.4275	46.5
1.3742	73.9	1.3840	68.4	1.3941	62.9	1.4048	57.4	1.4160	51.9	1.4277	46.4
1.3744	73.8	1.3842	68.3	1.3943	62.8	1.4050	57.3	1.4162	51.8	1.4279	46.3
1.3745	73.7	1.3843	68.2	1.3945	62.7	1.4052	57.2	1.4164	51.7	1.4281	46.2
1.3747	73.6	1.3845	68.1	1.3947	62.6	1.4054	57.1	1.4166	51.6	1.4283	46.1
1.3749	73.5	1.3847	68.0	1.3949	62.5	1.4056	57.0	1.4169	51.5	1.4285	46.0
1.3751	73.4	1.3849	67.9	1.3950	62.4	1.4058	56.9	1.4171	51.4	1.4287	45.9
1.3753	73.3	1.3851	67.8	1.3952	62.3	1.4060	56.8	1.4173	51.3	1.4289	45.8
1.3754	73.2	1.3852	67.7	1.3954	62.2	1.4062	56.7	1.4175	51.2	1.4292	45.7
1.3756	73.1	1.3854	67.6	1.3956	62.1	1.4064	56.6	1.4177	51.1	1.4294	45.6
1.3758	73.0	1.3856	67.5	1.3958	62.0	1.4066	56.5	1.4179	51.0	1.4296	45.5
1.3760	72.9	1.3858	67.4	1.3960	61.9	1.4068	56.4	1.4181	50.9	1.4298	45.4
1.3761	72.8	1.3860	67.3	1.3962	61.8	1.4070	56.3	1.4183	50.8	1.4300	45.3
1.3763	72.7	1.3861	67.2	1.3964	61.7	1.4072	56.2	1.4185	50.7	1.4303	45.2
1.3765	72.6	1.3863	67.1	1.3966	61.6	1.4074	56.1	1.4187	50.6	1.4305	45.1
1.3767	72.5	1.3865	67.0	1.3968	61.5	1.4076	56.0	1.4189	50.5	1.4307	45.0
1.3768	72.4	1.3867	66.9	1.3970	61.4	1.4078	55.9	1.4192	50.4	1.4309	44.9
1.3770	72.3	1.3869	66.8	1.3972	61.3	1.4080	55.8	1.4194	50.3	1.4311	44.8
1.3772	72.2	1.3870	66.7	1.3974	61.2	1.4082	55.7	1.4196	50.2	1.4313	44.7
1.3773	72.1	1.3872	66.6	1.3976	61.1	1.4084	55.6	1.4198	50.1	1.4316	44.6
1.3775	72.0	1.3874	66.5	1.3978	61.0	1.4086	55.5	1.4200	50.0	1.4318	44.5
1.3777	71.9	1.3876	66.4	1.3980	60.9	1.4088	55.4	1.4202	49.9	1.4320	44.4
1.3779	71.8	1.3878	66.3	1.3982	60.8	1.4090	55.3	1.4204	49.8	1.4322	44.3
1.3780	71.7	1.3879	66.2	1.3984	60.7	1.4092	55.2	1.4206	49.7	1.4325	44.2
1.3782	71.6	1.3881	66.1	1.3986	60.6	1.4094	55.1	1.4208	49.6	1.4327	44.1
1.3784	71.5	1.3883	66.0	1.3987	60.5	1.4096	55.0	1.4211	49.5	1.4329	44.0
1.3786	71.4	1.3885	65.9	1.3989	60.4	1.4098	54.9	1.4213	49.4	1.4331	43.9
1.3788	71.3	1.3887	65.8	1.3991	60.3	1.4100	54.8	1.4215	49.3	1.4333	43.8
1.3789	71.2	1.3889	65.7	1.3993	60.2	1.4102	54.7	1.4217	49.2	1.4336	43.7
1.3791	71.1	1.3891	65.6	1.3995	60.1	1.4104	54.6	1.4219	49.1	1.4338	43.6
1.3793	71.0	1.3893	65.5	1.3997	60.0	1.4107	54.5	1.4221	49.0	1.4340	43.5
1.3795	70.9	1.3894	65.4	1.3999	59.9	1.4109	54.4	1.4223	48.9	1.4342	43.4
1.3797	70.8	1.3896	65.3	1.4001	59.8	1.4111	54.3	1.4225	48.8	1.4344	43.3
1.3798	70.7	1.3898	65.2	1.4003	59.7	1.4113	54.2	1.4227	48.7	1.4347	43.2
1.3800	70.6	1.3900	65.1	1.4005	59.6	1.4115	54.1	1.4229	48.6	1.4349	43.1
1.3802	70.5	1.3902	65.0	1.4007	59.5	1.4117	54.0	1.4231	48.5	1.4351	43.0
1.3804	70.4	1.3904	64.9	1.4008	59.4	1.4119	53.9	1.4234	48.4	1.4353	42.9
1.3806	70.3	1.3906	64.8	1.4010	59.3	1.4121	53.8	1.4236	48.3	1.4355	42.8
1.3807	70.2	1.3907	64.7	1.4012	59.2	1.4123	53.7	1.4238	48.2	1.4358	42.7
1.3809	70.1	1.3909	64.6	1.4014	59.1	1.4125	53.6	1.4240	48.1	1.4360	42.6
1.3811	70.0	1.3911	64.5	1.4016	59.0	1.4127	53.5	1.4242	48.0	1.4362	42.5
1.3813	69.9	1.3913	64.4	1.4018	58.9	1.4129	53.4	1.4244	47.9	1.4364	42.4
1.3815	69.8	1.3915	64.3	1.4020	58.8	1.4131	53.3	1.4246	47.8	1.4366	42.3
1.3816	69.7	1.3916	64.2	1.4022	58.7	1.4133	53.2	1.4249	47.7	1.4369	42.2
1.3818	69.6	1.3918	64.1	1.4024	58.6	1.4135	53.1	1.4251	47.6	1.4371	42.1
1.3820	69.5	1.3920	64.0	1.4026	58.5	1.4137	53.0	1.4253	47.5	1.4373	42.0
1.3822	69.4	1.3922	63.9	1.4028	58.4	1.4139	52.9	1.4255	47.4	1.4375	41.9
1.3824	69.3	1.3924	63.8	1.4030	58.3	1.4141	52.8	1.4257	47.3	1.4378	41.8
1.3825	69.2	1.3926	63.7	1.4032	58.2	1.4143	52.7	1.4260	47.2	1.4380	41.7
1.3827	69.1	1.3928	63.6	1.4034	58.1	1.4145	52.6	1.4262	47.1	1.4382	41.6



$n_D^{20}$	%H <sub>2</sub> O	$n_D^{20}$	%H <sub>2</sub> O	$n_D^{20}$	%H <sub>2</sub> O	$n_D^{20}$	%H <sub>2</sub> O	$n_D^{20}$	%H <sub>2</sub> O	$n_D^{20}$	%H <sub>2</sub> O
1.4385	41.5	1.4509	36.0	1.4637	30.6	1.4772	25.1	1.4860	21.6	1.4951	18.1
1.4387	41.4	1.4511	35.9	1.4639	30.5	1.4774	25.0	1.4863	21.5	1.4954	18.0
1.4389	41.3	1.4514	35.8	1.4642	30.4	1.4777	24.9	1.4865	21.4	1.4956	17.9
1.4391	41.2	1.4516	35.7	1.4644	30.3	1.4779	24.8	1.4868	21.3	1.4959	17.8
1.4394	41.1	1.4518	35.6	1.4646	30.2	1.4782	24.7	1.4871	21.2	1.4962	17.7
1.4396	41.0	1.4521	35.5	1.4649	30.1	1.4784	24.6	1.4873	21.1	1.4964	17.6
1.4398	40.9	1.4523	35.4	1.4651	30.0	1.4787	24.5	1.4876	21.0	1.4967	17.5
1.4400	40.8	1.4525	35.3	1.4653	29.9	1.4789	24.4	1.4878	20.9	1.4970	17.4
1.4403	40.7	1.4527	35.2	1.4656	29.8	1.4792	24.3	1.4881	20.8	1.4972	17.3
1.4405	40.6	1.4530	35.1	1.4658	29.7	1.4794	24.2	1.4883	20.7	1.4975	17.2
1.4407	40.5	1.4532	35.0	1.4661	29.6	1.4797	24.1	1.4886	20.6	1.4978	17.1
1.4409	40.4	1.4534	34.9	1.4663	29.5	1.4799	24.0	1.4888	20.5	1.4980	17.0
1.4411	40.3	1.4537	34.8	1.4666	29.4	1.4802	23.9	1.4891	20.4	1.4983	16.9
1.4414	40.2	1.4539	34.7	1.4668	29.3	1.4804	23.8	1.4893	20.3	1.4985	16.8
1.4416	40.1	1.4541	34.6	1.4671	29.2	1.4807	23.7	1.4896	20.2	1.4988	16.7
1.4418	40.0	1.4544	34.5	1.4673	29.1	1.4810	23.6	1.4898	20.1	1.4991	16.6
1.4420	39.9	1.4546	34.4	1.4676	29.0	1.4812	23.5	1.4901	20.0	1.4993	16.5
1.4423	39.8	1.4548	34.3	1.4678	28.9	1.4815	23.4	1.4904	19.9	1.4996	16.4
1.4425	39.7	1.4550	34.2	1.4681	28.8	1.4817	23.3	1.4906	19.8	1.4999	16.3
1.4427	39.6	1.4553	34.1	1.4683	28.7	1.4820	23.2	1.4909	19.7	1.5001	16.2
1.4429	39.5	1.4555	34.0*	1.4685	28.6	1.4822	23.1	1.4912	19.6	1.5004	16.1
1.4432	39.4	1.4558	34.0	1.4688	28.5	1.4825	23.0	1.4914	19.5	1.5007	16.0
1.4434	39.3	1.4561	33.9	1.4690	28.4	1.4827	22.9	1.4917	19.4	1.5009	15.9
1.4436	39.2	1.4563	33.8	1.4693	28.3	1.4830	22.8	1.4919	19.3	1.5012	15.8
1.4439	39.1	1.4565	33.7	1.4695	28.2	1.4832	22.7	1.4922	19.2	1.5015	15.7
1.4441	39.0	1.4567	33.6	1.4698	28.1	1.4835	22.6	1.4925	19.1	1.5017	15.6
1.4443	38.9	1.4570	33.5	1.4700	28.0	1.4838	22.5	1.4927	19.0	1.5020	15.5
1.4446	38.8	1.4572	33.4	1.4703	27.9	1.4840	22.4	1.4930	18.9	1.5022	15.4
1.4448	38.7	1.4574	33.3	1.4705	27.8	1.4843	22.3	1.4933	18.8	1.5025	15.3
1.4450	38.6	1.4577	33.2	1.4708	27.7	1.4845	22.2	1.4935	18.7	1.5028	15.2
1.4453	38.5	1.4579	33.1	1.4710	27.6	1.4848	22.1	1.4938	18.6	1.5030	15.1
1.4455	38.4	1.4581	33.0	1.4713	27.5	1.4850	22.0	1.4941	18.5	1.5033	15.0
1.4457	38.3	1.4584	32.9	1.4715	27.4	1.4853	21.9	1.4943	18.4		
1.4459	38.2	1.4586	32.8	1.4717	27.3	1.4855	21.8	1.4946	18.3		
1.4462	38.1	1.4588	32.7	1.4720	27.2	1.4858	21.7	1.4949	18.2		
1.4464	38.0	1.4591	32.6	1.4722	27.1						
1.4466	37.9	1.4593	32.5	1.4725	27.0						
1.4468	37.8	1.4595	32.4	1.4727	26.9						
1.4471	37.7	1.4598	32.3	1.4730	26.8						
1.4473	37.6	1.4600	32.2	1.4732	26.7						
1.4475	37.5	1.4602	32.1	1.4735	26.6						
1.4477	37.4	1.4605	32.0	1.4737	26.5						
1.4479	37.3	1.4607	31.9	1.4740	26.4						
1.4482	37.2	1.4609	31.8	1.4742	26.3						
1.4484	37.1	1.4612	31.7	1.4744	26.2						
1.4486	37.0	1.4614	31.6	1.4747	26.1						
1.4488	36.9	1.4616	31.5	1.4749	26.0						
1.4491	36.8	1.4619	31.4	1.4752	25.9						
1.4493	36.7	1.4621	31.3	1.4754	25.8						
1.4495	36.6	1.4623	31.2	1.4757	25.7						
1.4497	36.5	1.4625	31.1	1.4759	25.6						
1.4500	36.4	1.4628	31.0	1.4762	25.5						
1.4502	36.3	1.4630	30.9	1.4764	25.4						
1.4504	36.2	1.4632	30.8	1.4767	25.3						
1.4507	36.1	1.4635	30.7	1.4769	25.2						

\* The values of the refractive index from 34 to 15% are taken from Main's table (61.5).

REFRACTIVE INDEX CORRECTION TABLE FOR READINGS AT TEMPERATURES OTHER THAN 20°C (86)

%H <sub>2</sub> O	95	90	85	80	70	60	50	40	30	25
°C	To be added to % water									
15	0.25	0.27	0.31	0.31	0.34	0.35	0.36	0.37	0.36	0.36
16	0.21	0.23	0.26	0.27	0.29	0.31	0.31	0.32	0.31	0.29
17	0.16	0.18	0.20	0.20	0.22	0.23	0.23	0.23	0.20	0.17
18	0.11	0.12	0.14	0.14	0.15	0.16	0.16	0.15	0.12	0.09
19	0.06	0.07	0.08	0.08	0.08	0.09	0.09	0.08	0.07	0.05
	To be subtracted from % water									
21	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
22	0.12	0.14	0.14	0.14	0.14	0.14	0.15	0.14	0.14	0.14
23	0.18	0.20	0.20	0.21	0.21	0.21	0.23	0.21	0.22	0.22
24	0.24	0.26	0.26	0.27	0.28	0.28	0.30	0.28	0.29	0.29
25	0.30	0.32	0.32	0.34	0.36	0.36	0.38	0.36	0.36	0.37
26	0.36	0.39	0.39	0.41	0.43	0.43	0.46	0.44	0.43	0.44
27	0.43	0.46	0.46	0.48	0.50	0.51	0.55	0.52*	0.50	0.51
28	0.50	0.53	0.53	0.55	0.58	0.59	0.63	0.60*	0.57	0.59
29	0.57	0.60	0.61	0.62	0.66	0.67	0.71	0.68*	0.65	0.67
30	0.64	0.67	0.70	0.71	0.74	0.75	0.80	0.76*	0.73	0.75
% H <sub>2</sub> O	95	90	85	80	70	60	50	40	30	25

\* These are corrected values. Stanek's original table gives values 0.10 higher.

TABLE FOR USE WITH ZEISS IMMERSION REFRACTOMETER (57.5)  $R$  = scale reading; %  $S$  = % sucrose

$R$	% $S$	$R$	% $S$	$R$	% $S$	$R$	% $S$	$R$	% $S$	$R$	% $S$	$R$	% $S$	$R$	% $S$
15.0	0.00	21.0	1.58	27.0	3.16	33.0	4.74	39.0	6.31	45.0	7.84	51.0	9.32	57.0	10.78
.1	.03	.1	.61	.1	.19	.1	.77	.1	.33	.1	.87	.1	.34	.1	.80
.2	.05	.2	.64	.2	.21	.2	.79	.2	.36	.2	.90	.2	.36	.2	.83
.3	.08	.3	.66	.3	.24	.3	.82	.3	.39	.3	.92	.3	.39	.3	.85
.4	.11	.4	.69	.4	.26	.4	.84	.4	.41	.4	.95	.4	.41	.4	.88
.5	.13	.5	.71	.5	.29	.5	.87	.5	.43	.5	.97	.5	.44	.5	.90
.6	.16	.6	.74	.6	.32	.6	.90	.6	.46	.6	8.00	.6	.46	.6	.92
.7	.19	.7	.77	.7	.34	.7	.92	.7	.49	.7	.03	.7	.49	.7	.95
.8	.21	.8	.79	.8	.37	.8	.95	.8	.51	.8	.05	.8	.51	.8	.97
.9	.24	.9	.82	.9	.40	.9	.98	.9	.54	.9	.07	.9	.53	.9	11.00
16.0	.26	22.0	.84	28.0	.42	34.0	5.00	40.0	.56	46.0	.10	52.0	.56	58.0	.03
.1	.29	.1	.87	.1	.45	.1	.03	.1	.59	.1	.12	.1	.58	.1	.05
.2	.32	.2	.90	.2	.48	.2	.05	.2	.61	.2	.15	.2	.60	.2	.07
.3	.34	.3	.92	.3	.50	.3	.08	.3	.64	.3	.17	.3	.63	.3	.10
.4	.37	.4	.95	.4	.53	.4	.11	.4	.66	.4	.19	.4	.66	.4	.12
.5	.40	.5	.98	.5	.56	.5	.13	.5	.69	.5	.22	.5	.68	.5	.15
.6	.42	.6	2.00	.6	.58	.6	.16	.6	.72	.6	.24	.6	.70	.6	.17
.7	.45	.7	.03	.7	.61	.7	.19	.7	.74	.7	.27	.7	.73	.7	.19
.8	.48	.8	.05	.8	.64	.8	.21	.8	.77	.8	.29	.8	.75	.8	.22
.9	.50	.9	.08	.9	.66	.9	.24	.9	.79	.9	.32	.9	.78	.9	.24
17.0	.53	23.0	.11	29.0	.69	35.0	.26	41.0	.82	47.0	.34	53.0	.80	59.0	.27
.1	.56	.1	.13	.1	.71	.1	.29	.1	.84	.1	.36	.1	.83	.1	.29
.2	.58	.2	.16	.2	.74	.2	.32	.2	.87	.2	.39	.2	.85	.2	.32
.3	.61	.3	.19	.3	.77	.3	.34	.3	.90	.3	.41	.3	.88	.3	.34
.4	.64	.4	.21	.4	.79	.4	.37	.4	.92	.4	.44	.4	.90	.4	.36
.5	.66	.5	.24	.5	.82	.5	.40	.5	.95	.5	.46	.5	.92	.5	.39
.6	.69	.6	.26	.6	.84	.6	.42	.6	.97	.6	.49	.6	.95	.6	.41
.7	.71	.7	.29	.7	.87	.7	.45	.7	7.00	.7	.51	.7	.97	.7	.44
.8	.74	.8	.32	.8	.90	.8	.48	.8	.03	.8	.53	.8	10.00	.8	.46
.9	.77	.9	.34	.9	.92	.9	.50	.9	.05	.9	.56	.9	.03	.9	.49
18.0	.79	24.0	.37	30.0	.95	36.0	.53	42.0	.08	48.0	.58	54.0	.05	60.0	.51
.1	.82	.1	.40	.1	.98	.1	.56	.1	.10	.1	.60	.1	.07	.1	.53
.2	.84	.2	.42	.2	4.00	.2	.58	.2	.13	.2	.63	.2	.10	.2	.56
.3	.87	.3	.45	.3	.03	.3	.61	.3	.15	.3	.66	.3	.12	.3	.58
.4	.90	.4	.48	.4	.05	.4	.64	.4	.18	.4	.68	.4	.15	.4	.60
.5	.92	.5	.50	.5	.08	.5	.66	.5	.20	.5	.70	.5	.17	.5	.63
.6	.95	.6	.53	.6	.11	.6	.69	.6	.23	.6	.73	.6	.19	.6	.66
.7	.98	.7	.56	.7	.13	.7	.71	.7	.26	.7	.75	.7	.22	.7	.68
.8	1.00	.8	.58	.8	.16	.8	.74	.8	.28	.8	.78	.8	.24	.8	.70
.9	.03	.9	.61	.9	.19	.9	.77	.9	.31	.9	.80	.9	.27	.9	.73
19.0	.05	25.0	.64	31.0	.21	37.0	.79	43.0	.33	49.0	.83	55.0	.29	61.0	.75
.1	.08	.1	.66	.1	.24	.1	.82	.1	.36	.1	.85	.1	.32	.1	.78
.2	.11	.2	.69	.2	.26	.2	.84	.2	.39	.2	.88	.2	.34	.2	.80
.3	.13	.3	.71	.3	.29	.3	.87	.3	.41	.3	.90	.3	.36	.3	.83
.4	.16	.4	.74	.4	.32	.4	.90	.4	.43	.4	.92	.4	.39	.4	.85
.5	.19	.5	.77	.5	.34	.5	.92	.5	.46	.5	.95	.5	.41	.5	.88
.6	.21	.6	.79	.6	.37	.6	.95	.6	.49	.6	.97	.6	.44	.6	.90
.7	.24	.7	.82	.7	.39	.7	.98	.7	.51	.7	9.00	.7	.46	.7	.92
.8	.26	.8	.84	.8	.42	.8	6.00	.8	.54	.8	.03	.8	.49	.8	.95
.9	.29	.9	.87	.9	.45	.9	.03	.9	.56	.9	.05	.9	.51	.9	.97
20.0	.32	26.0	.90	32.0	.48	38.0	.05	44.0	.59	50.0	.07	56.0	.53	62.0	12.00
.1	.34	.1	.92	.1	.50	.1	.08	.1	.61	.1	.10	.1	.56	.1	.03
.2	.37	.2	.95	.2	.53	.2	.10	.2	.64	.2	.12	.2	.58	.2	.05
.3	.40	.3	.98	.3	.56	.3	.13	.3	.66	.3	.15	.3	.60	.3	.07
.4	.42	.4	3.00	.4	.58	.4	.15	.4	.69	.4	.17	.4	.63	.4	.09
.5	.45	.5	.03	.5	.61	.5	.17	.5	.72	.5	.19	.5	.66	.5	.12
.6	.48	.6	.05	.6	.64	.6	.20	.6	.74	.6	.22	.6	.68	.6	.14
.7	.50	.7	.08	.7	.66	.7	.23	.7	.77	.7	.24	.7	.70	.7	.16
.8	.53	.8	.11	.8	.69	.8	.26	.8	.79	.8	.27	.8	.73	.8	.18
.9	.56	.9	.13	.9	.71	.9	.28	.9	.82	.9	.29	.9	.75	.9	.21



<i>R</i>	% <i>S</i>	<i>R</i>	% <i>S</i>	<i>R</i>	% <i>S</i>	<i>R</i>	% <i>S</i>	<i>R</i>	% <i>S</i>	<i>R</i>	% <i>S</i>	<i>R</i>	% <i>S</i>	<i>R</i>	% <i>S</i>
63.0	12.23	69.0	13.61	75.0	14.98	81.0	16.31	87.0	17.66	92.0	18.74	97.0	19.80	102.0	20.87
.1	.25	.1	.63	.1	15.00	.1	.33	.1	.68	.1	.76	.1	.82	.1	.89
.2	.28	.2	.66	.2	.03	.2	.35	.2	.71	.2	.78	.2	.85	.2	.91
.3	.30	.3	.68	.3	.05	.3	.38	.3	.73	.3	.80	.3	.87	.3	.93
.4	.32	.4	.70	.4	.07	.4	.40	.4	.75	.4	.82	.4	.89	.4	.95
.5	.35	.5	.73	.5	.09	.5	.42	.5	.77	.5	.85	.5	.91	.5	.97
.6	.37	.6	.75	.6	.11	.6	.44	.6	.79	.6	.87	.6	.93	.6	21.00
.7	.39	.7	.77	.7	.13	.7	.47	.7	.82	.7	.89	.7	.95	.7	.02
.8	.42	.8	.79	.8	.16	.8	.49	.8	.84	.8	.91	.8	.97	.8	.04
.9	.44	.9	.82	.9	.18	.9	.51	.9	.86	.9	.93	.9	20.00	.9	.06
64.0	.46	70.0	.84	76.0	.20	82.0	.54	88.0	.89	93.0	.95	98.0	.02	103.0	.08
.1	.49	.1	.87	.1	.22	.1	.56	.1	.91	.1	.97	.1	.04	.1	.10
.2	.51	.2	.89	.2	.24	.2	.59	.2	.93	.2	19.00	.2	.06	.2	.13
.3	.53	.3	.92	.3	.26	.3	.61	.3	.95	.3	.02	.3	.08	.3	.15
.4	.56	.4	.94	.4	.28	.4	.63	.4	.98	.4	.04	.4	.10	.4	.17
.5	.58	.5	.96	.5	.30	.5	.65	.5	18.00	.5	.06	.5	.13	.5	.19
.6	.60	.6	.98	.6	.32	.6	.68	.6	.02	.6	.08	.6	.15	.6	.21
.7	.63	.7	14.00	.7	.34	.7	.70	.7	.04	.7	.10	.7	.17	.7	.23
.8	.65	.8	.03	.8	.36	.8	.72	.8	.06	.8	.13	.8	.19	.8	.25
.9	.67	.9	.05	.9	.38	.9	.74	.9	.08	.9	.15	.9	.21	.9	.27
65.0	.69	71.0	.07	77.0	.40	83.0	.76	89.0	.10	94.0	.17	99.0	.23	104.0	.29
.1	.72	.1	.09	.1	.42	.1	.79	.1	.13	.1	.19	.1	.25	.1	.31
.2	.74	.2	.11	.2	.44	.2	.81	.2	.15	.2	.21	.2	.27	.2	.34
.3	.76	.3	.14	.3	.47	.3	.83	.3	.17	.3	.23	.3	.29	.3	.36
.4	.79	.4	.16	.4	.49	.4	.85	.4	.19	.4	.25	.4	.31	.4	.38
.5	.81	.5	.18	.5	.51	.5	.88	.5	.21	.5	.27	.5	.34	.5	.40
.6	.83	.6	.20	.6	.54	.6	.90	.6	.23	.6	.29	.6	.36	.6	.42
.7	.86	.7	.23	.7	.56	.7	.92	.7	.25	.7	.31	.7	.38	.7	.44
.8	.88	.8	.25	.8	.59	.8	.95	.8	.27	.8	.34	.8	.40	.8	.47
.9	.90	.9	.27	.9	.61	.9	.97	.9	.29	.9	.36	.9	.42	.9	.49
66.0	.93	72.0	.29	78.0	.63	84.0	17.00	90.0	.31	95.0	.38	100.0	.44	105.0	.51
.1	.95	.1	.32	.1	.65	.1	.02	.1	.34	.1	.40	.1	.47	.1	.53
.2	.97	.2	.34	.2	.68	.2	.04	.2	.36	.2	.42	.2	.49	.2	.55
.3	13.00	.3	.36	.3	.70	.3	.07	.3	.38	.3	.44	.3	.51	.3	.57
.4	.03	.4	.38	.4	.72	.4	.09	.4	.40	.4	.47	.4	.53	.4	.59
.5	.05	.5	.40	.5	.74	.5	.11	.5	.42	.5	.49	.5	.55	.5	.61
.6	.07	.6	.43	.6	.76	.6	.13	.6	.44	.6	.51	.6	.57	.6	.63
.7	.09	.7	.45	.7	.79	.7	.15	.7	.47	.7	.53	.7	.59	.7	.66
.8	.11	.8	.48	.8	.81	.8	.18	.8	.49	.8	.55	.8	.61	.8	.68
.9	.14	.9	.50	.9	.83	.9	.20	.9	.51	.9	.57	.9	.63	.9	.70
67.0	.16	73.0	.52	79.0	.85	85.0	.22	91.0	.53	96.0	.59	101.0	.66	106.0	.71
.1	.18	.1	.54	.1	.88	.1	.24	.1	.55	.1	.61	.1	.68		
.2	.20	.2	.57	.2	.90	.2	.27	.2	.57	.2	.63	.2	.70		
.3	.23	.3	.59	.3	.92	.3	.29	.3	.59	.3	.66	.3	.72		
.4	.25	.4	.61	.4	.95	.4	.31	.4	.61	.4	.68	.4	.74		
.5	.27	.5	.63	.5	.97	.5	.33	.5	.63	.5	.70	.5	.76		
.6	.29	.6	.66	.6	16.00	.6	.35	.6	.66	.6	.72	.6	.78		
.7	.32	.7	.68	.7	.03	.7	.38	.7	.68	.7	.74	.7	.80		
.8	.34	.8	.70	.8	.05	.8	.40	.8	.70	.8	.76	.8	.82		
.9	.36	.9	.73	.9	.07	.9	.42	.9	.72	.9	.78	.9	.85		
68.0	.38	74.0	.75	80.0	.09	86.0	.44								
.1	.40	.1	.77	.1	.11	.1	.47								
.2	.43	.2	.79	.2	.13	.2	.49								
.3	.45	.3	.82	.3	.16	.3	.51								
.4	.48	.4	.84	.4	.18	.4	.53								
.5	.50	.5	.87	.5	.20	.5	.55								
.6	.52	.6	.89	.6	.22	.6	.58								
.7	.54	.7	.92	.7	.24	.7	.60								
.8	.57	.8	.94	.8	.27	.8	.62								
.9	.59	.9	.96	.9	.29	.9	.64								

DRY SUBSTANCE (*D*) IN SUGAR-HOUSE PRODUCTS AT 28°C (76)

$n_D^{28}$	% <i>D</i>	Decimals	
1.3335	1	0.0001=0.05	0.0010=0.75
1.3349	2	0.0002=0.1	0.0011=0.8
1.3364	3	0.0003=0.2	0.0012=0.8
1.3379	4	0.0004=0.25	0.0013=0.85
1.3394	5	0.0005=0.3	0.0014=0.9
1.3409	6	0.0006=0.4	0.0015=1.0
1.3424	7	0.0007=0.5	
1.3439	8	0.0008=0.6	
1.3454	9	0.0009=0.7	
1.3469	10		
1.3484	11	0.0001=0.05	
1.3500	12	0.0002=0.1	
1.3516	13	0.0003=0.2	
1.3530	14	0.0004=0.25	
1.3546	15	0.0005=0.3	
1.3562	16	0.0006=0.4	
1.3578	17	0.0007=0.45	
1.3594	18	0.0008=0.5	
1.3611	19	0.0009=0.6	
1.3627	20	0.0010=0.65	
1.3644	21	0.0011=0.7	
1.3661	22	0.0012=0.75	
1.3678	23	0.0013=0.8	
1.3695	24	0.0014=0.85	
1.3712	25	0.0015=0.9	
1.3729	26	0.0016=0.95	
1.3746	27		
1.3764	28		
1.3782	29	0.0001=0.05	0.0012=0.6
1.3800	30	0.0002=0.1	0.0013=0.65
1.3818	31	0.0003=0.15	0.0014=0.7
1.3836	32	0.0004=0.2	0.0015=0.75
1.3854	33	0.0005=0.25	0.0016=0.8
1.3872	34	0.0006=0.3	0.0017=0.85
1.3890	35	0.0007=0.35	0.0018=0.9
1.3909	36	0.0008=0.4	0.0019=0.95
1.3928	37	0.0009=0.45	0.0020=1.0
1.3947	38	0.0010=0.5	0.0021=1.0
1.3966	39	0.0011=0.55	
1.3984	40		
1.4003	41		
1.4023	42		
1.4043	43	0.0001=0.05	0.0012=0.6
1.4063	44	0.0002=0.1	0.0013=0.65
1.4083	45	0.0003=0.15	0.0014=0.7
1.4104	46	0.0004=0.2	0.0015=0.75
1.4124	47	0.0005=0.25	0.0016=0.8
1.4145	48	0.0006=0.3	0.0017=0.85
1.4166	49	0.0007=0.35	0.0018=0.9
1.4186	50	0.0008=0.4	0.0019=0.95
1.4207	51	0.0009=0.45	0.0020=1.0
1.4228	52	0.0010=0.5	0.0021=1.0
1.4249	53	0.0011=0.55	
1.4270	54		
1.4292	55	0.0001=0.05	0.0013=0.55
1.4314	56	0.0002=0.1	0.0014=0.6
1.4337	57	0.0003=0.1	0.0015=0.65
1.4359	58	0.0004=0.15	0.0016=0.7
1.4382	59	0.0005=0.2	0.0017=0.75
1.4405	60	0.0006=0.25	0.0018=0.8
1.4428	61	0.0007=0.3	0.0019=0.85
1.4451	62	0.0008=0.35	0.0020=0.9
1.4474	63	0.0009=0.4	0.0021=0.9

DRY SUBSTANCE (*D*) IN SUGAR-HOUSE PRODUCTS AT 28°C (76).—  
(Continued)

$n_D^{28}$	% <i>D</i>	Decimals	
1.4497	64	0.0010=0.45	0.0022=0.95
1.4520	65	0.0011=0.5	0.0023=1.0
1.4543	66	0.0012=0.5	0.0024=1.0
1.4567	67		
1.4591	68		
1.4615	69		
1.4639	70		
1.4663	71		
1.4687	72		
1.4711	73		
1.4736	74		
1.4761	75	0.0001=0.0	0.0015=0.55
1.4786	76	0.0002=0.05	0.0016=0.6
1.4811	77	0.0003=0.1	0.0017=0.65
1.4836	78	0.0004=0.15	0.0018=0.65
1.4862	79	0.0005=0.2	0.0019=0.7
1.4888	80	0.0006=0.2	0.0020=0.75
1.4914	81	0.0007=0.25	0.0021=0.8
1.4940	82	0.0008=0.3	0.0022=0.8
1.4966	83	0.0009=0.35	0.0023=0.85
1.4992	84	0.0010=0.35	0.0024=0.9
1.5019	85	0.0011=0.4	0.0025=0.9
1.5046	86	0.0012=0.45	0.0026=0.95
1.5073	87	0.0013=0.5	0.0027=1.0
1.5100	88	0.0014=0.5	0.0028=1.0
1.5127	89		
1.5155	90		

CORRECTIONS FOR THE TEMPERATURE (76)

% <i>D</i>	Dry substance													
	0	5	10	15	20	25	30	40	50	60	70	80	90	
°C	Subtract													
20	0.53	0.54	0.55	0.56	0.57	0.58	0.60	0.62	0.64	0.62	0.61	0.60	0.58	
21	0.46	0.47	0.48	0.49	0.50	0.51	0.52	0.54	0.56	0.54	0.53	0.52	0.50	
22	0.40	0.41	0.42	0.42	0.43	0.44	0.45	0.47	0.48	0.47	0.46	0.45	0.44	
23	0.33	0.33	0.34	0.35	0.36	0.37	0.38	0.39	0.40	0.39	0.38	0.38	0.38	
24	0.26	0.26	0.27	0.28	0.28	0.29	0.30	0.31	0.32	0.31	0.31	0.30	0.30	
25	0.20	0.20	0.21	0.21	0.22	0.22	0.23	0.23	0.24	0.23	0.23	0.23	0.22	
26	0.12	0.12	0.13	0.14	0.14	0.14	0.15	0.15	0.16	0.16	0.16	0.15	0.14	
27	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.07	
	Add													
29	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.07	
30	0.12	0.12	0.13	0.14	0.14	0.14	0.15	0.15	0.16	0.16	0.16	0.15	0.14	
31	0.20	0.20	0.21	0.21	0.22	0.22	0.23	0.23	0.24	0.23	0.23	0.23	0.22	
32	0.26	0.26	0.27	0.28	0.28	0.29	0.30	0.31	0.32	0.31	0.31	0.30	0.30	
33	0.33	0.33	0.34	0.35	0.36	0.37	0.38	0.39	0.40	0.39	0.38	0.38	0.38	
34	0.40	0.41	0.42	0.42	0.43	0.44	0.45	0.47	0.48	0.47	0.46	0.45	0.44	
35	0.46	0.47	0.48	0.49	0.50	0.51	0.52	0.54	0.56	0.54	0.53	0.52	0.50	

## Density of Aqueous Sucrose Solutions at 20°C, g/ml

All weights *in vacuo*. For hydrometer conversion formulae see vol. I, p. 31 and for computed conversion tables and temperature corrections *v.* (17.5, 61.5, 75). For conversion table giving deg. Brix,  $d_4^{20}$ ,  $d_{20}^{20}$  and deg. Baumé, based upon the formula, °Bé = 145 - 145/sp. gr.,  $d_{20}^{20}$  *v.* (7).



DENSITY OF AQUEOUS SUCROSE SOLUTIONS AT 20°C, g/ml.

% sucrose	$d_4^{20}$									
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	0.998234	0.998622	0.999010	0.999398	0.999786	1.000174	1.000563	1.000952	1.001342	1.001731
1	1.002120	1.002509	1.002897	1.003286	1.003675	1.004064	1.004453	1.004844	1.005234	1.005624
2	1.006015	1.006405	1.006796	1.007188	1.007580	1.007972	1.008363	1.008755	1.009148	1.009541
3	1.009934	1.010327	1.010721	1.011115	1.011510	1.011904	1.012298	1.012694	1.013089	1.013485
4	1.013881	1.014277	1.014673	1.015070	1.015467	1.015864	1.016261	1.016659	1.017058	1.017456
5	1.017854	1.018253	1.018652	1.019052	1.019451	1.019851	1.020251	1.020651	1.021053	1.021454
6	1.021855	1.022257	1.022659	1.023061	1.023463	1.023867	1.024270	1.024673	1.025077	1.025481
7	1.025885	1.026289	1.026694	1.027099	1.027504	1.027910	1.028316	1.028722	1.029128	1.029535
8	1.029942	1.030349	1.030757	1.031165	1.031573	1.031982	1.032391	1.032800	1.033209	1.033619
9	1.034029	1.034439	1.034850	1.035260	1.035671	1.036082	1.036494	1.036906	1.037318	1.037730
10	1.038143	1.038556	1.038970	1.039383	1.039797	1.040212	1.040626	1.041041	1.041456	1.041872
11	1.042288	1.042704	1.043121	1.043537	1.043954	1.044370	1.044788	1.045206	1.045625	1.046043
12	1.046462	1.046881	1.047300	1.047720	1.048140	1.048559	1.048980	1.049401	1.049822	1.050243
13	1.050665	1.051087	1.051510	1.051933	1.052356	1.052778	1.053202	1.053626	1.054050	1.054475
14	1.054900	1.055325	1.055751	1.056176	1.056602	1.057029	1.057455	1.057882	1.058310	1.058737
15	1.059165	1.059593	1.060022	1.060451	1.060880	1.061308	1.061738	1.062168	1.062598	1.063029
16	1.063460	1.063892	1.064324	1.064756	1.065188	1.065621	1.066054	1.066487	1.066921	1.067355
17	1.067789	1.068223	1.068658	1.069093	1.069529	1.069964	1.070400	1.070836	1.071273	1.071710
18	1.072147	1.072585	1.073023	1.073461	1.073900	1.074338	1.074777	1.075217	1.075657	1.076097
19	1.076537	1.076978	1.077419	1.077860	1.078302	1.078744	1.079187	1.079629	1.080072	1.080515
20	1.080959	1.081403	1.081848	1.082292	1.082737	1.083182	1.083628	1.084074	1.084520	1.084967
21	1.085414	1.085861	1.086309	1.086757	1.087205	1.087652	1.088101	1.088550	1.089000	1.089450
22	1.089900	1.090351	1.090802	1.091253	1.091704	1.092155	1.092607	1.093060	1.093513	1.093966
23	1.094420	1.094874	1.095328	1.095782	1.096236	1.096691	1.097147	1.097603	1.098058	1.098514
24	1.098971	1.099428	1.099886	1.100344	1.100802	1.101259	1.101718	1.102177	1.102637	1.103097
25	1.103557	1.104017	1.104478	1.104938	1.105400	1.105862	1.106324	1.106786	1.107248	1.107711
26	1.108175	1.108639	1.109103	1.109568	1.110033	1.110497	1.110963	1.111429	1.111895	1.112361
27	1.112828	1.113295	1.113763	1.114229	1.114697	1.115166	1.115635	1.116104	1.116572	1.117042
28	1.117512	1.117982	1.118453	1.118923	1.119395	1.119867	1.120339	1.120812	1.121284	1.121757
29	1.122231	1.122705	1.123179	1.123653	1.124128	1.124603	1.125079	1.125555	1.126030	1.126507
30	1.126984	1.127461	1.127939	1.128417	1.128896	1.129374	1.129853	1.130332	1.130812	1.131292
31	1.131773	1.132254	1.132735	1.133216	1.133698	1.134180	1.134663	1.135146	1.135628	1.136112
32	1.136596	1.137080	1.137565	1.138049	1.138534	1.139020	1.139506	1.139993	1.140479	1.140966
33	1.141453	1.141941	1.142429	1.142916	1.143405	1.143894	1.144384	1.144874	1.145363	1.145854
34	1.146345	1.146836	1.147328	1.147820	1.148313	1.148805	1.149298	1.149792	1.150286	1.150780
35	1.151275	1.151770	1.152265	1.152760	1.153256	1.153752	1.154249	1.154746	1.155242	1.155740
36	1.156238	1.156736	1.157235	1.157733	1.158233	1.158733	1.159233	1.159733	1.160233	1.160734
37	1.161236	1.161738	1.162240	1.162742	1.163245	1.163748	1.164252	1.164756	1.165259	1.165764
38	1.166269	1.166775	1.167281	1.167786	1.168293	1.168800	1.169307	1.169815	1.170322	1.170831
39	1.171340	1.171849	1.172359	1.172869	1.173379	1.173889	1.174400	1.174911	1.175423	1.175935
40	1.176447	1.176960	1.177473	1.177987	1.178501	1.179014	1.179527	1.180044	1.180560	1.181076
41	1.181592	1.182108	1.182625	1.183142	1.183660	1.184178	1.184696	1.185215	1.185734	1.186253
42	1.186773	1.187293	1.187814	1.188335	1.188856	1.189379	1.189901	1.190423	1.190946	1.191469
43	1.191993	1.192517	1.193041	1.193565	1.194090	1.194616	1.195141	1.195667	1.196193	1.196720
44	1.197247	1.197775	1.198303	1.198832	1.199360	1.199890	1.200420	1.200950	1.201480	1.202010
45	1.202540	1.203071	1.203603	1.204136	1.204668	1.205200	1.205733	1.206266	1.206801	1.207335
46	1.207870	1.208405	1.208940	1.209477	1.210013	1.210549	1.211086	1.211623	1.212162	1.212700
47	1.213238	1.213777	1.214317	1.214856	1.215395	1.215936	1.216476	1.217017	1.217559	1.218101
48	1.218643	1.219185	1.219729	1.220272	1.220815	1.221360	1.221904	1.222449	1.222995	1.223540
49	1.224086	1.224632	1.225180	1.225727	1.226274	1.226823	1.227371	1.227919	1.228469	1.229018

DENSITY OF AQUEOUS SUCROSE SOLUTIONS AT 20°C, g/ml.—(Continued)

% sucrose	$d_4^{20}$									
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
50	1.229567	1.230117	1.230668	1.231219	1.231770	1.232322	1.232874	1.233426	1.233979	1.234532
51	1.235085	1.235639	1.236194	1.236748	1.237303	1.237859	1.238414	1.238970	1.239527	1.240084
52	1.240641	1.241198	1.241757	1.242315	1.242873	1.243433	1.243992	1.244552	1.245113	1.245673
53	1.246234	1.246795	1.247358	1.247920	1.248482	1.249046	1.249609	1.250172	1.250737	1.251301
54	1.251866	1.252431	1.252997	1.253563	1.254129	1.254697	1.255264	1.255831	1.256400	1.256967
55	1.257535	1.258104	1.258674	1.259244	1.259815	1.260385	1.260955	1.261527	1.262099	1.262671
56	1.263243	1.263816	1.264390	1.264963	1.265537	1.266112	1.266686	1.267261	1.267837	1.268413
57	1.268989	1.269565	1.270143	1.270720	1.271299	1.271877	1.272455	1.273035	1.273614	1.274194
58	1.274774	1.275354	1.275936	1.276517	1.277098	1.277680	1.278262	1.278844	1.279428	1.280011
59	1.280595	1.281179	1.281764	1.282349	1.282935	1.283521	1.284107	1.284694	1.285281	1.285869
60	1.286456	1.287044	1.287633	1.288222	1.288811	1.289401	1.289991	1.290581	1.291172	1.291763
61	1.292354	1.292946	1.293539	1.294131	1.294725	1.295318	1.295911	1.296506	1.297100	1.297696
62	1.298291	1.298886	1.299483	1.300079	1.300677	1.301274	1.301871	1.302470	1.303068	1.303668
63	1.304267	1.304867	1.305467	1.306068	1.306669	1.307271	1.307872	1.308475	1.309077	1.309680
64	1.310282	1.310885	1.311489	1.312093	1.312699	1.313304	1.313909	1.314515	1.315121	1.315728
65	1.316334	1.316941	1.317549	1.318157	1.318766	1.319374	1.319983	1.320593	1.321203	1.321814
66	1.322425	1.323036	1.323648	1.324259	1.324872	1.325484	1.326097	1.326711	1.327325	1.327940
67	1.328554	1.329170	1.329785	1.330401	1.331017	1.331633	1.332250	1.332868	1.333485	1.334103
68	1.334722	1.335342	1.335961	1.336581	1.337200	1.337821	1.338441	1.339063	1.339684	1.340306
69	1.340928	1.341551	1.342174	1.342798	1.343421	1.344046	1.344671	1.345296	1.345922	1.346547
70	1.347174	1.347801	1.348427	1.349055	1.349682	1.350311	1.350939	1.351568	1.352197	1.352827
71	1.353456	1.354087	1.354717	1.355349	1.355980	1.356612	1.357245	1.357877	1.358511	1.359144
72	1.359778	1.360413	1.361047	1.361682	1.362317	1.362953	1.363590	1.364226	1.364864	1.365501
73	1.366139	1.366777	1.367415	1.368054	1.368693	1.369333	1.369973	1.370613	1.371254	1.371894
74	1.372536	1.373178	1.373820	1.374463	1.375105	1.375749	1.376392	1.377036	1.377680	1.378326
75	1.378971	1.379617	1.380262	1.380909	1.381555	1.382203	1.382851	1.383499	1.384148	1.384796
76	1.385446	1.386096	1.386745	1.387396	1.388045	1.388696	1.389347	1.389999	1.390651	1.391303
77	1.391956	1.392610	1.393263	1.393917	1.394571	1.395226	1.395881	1.396536	1.397192	1.397848
78	1.398505	1.399162	1.399819	1.400477	1.401134	1.401793	1.402452	1.403111	1.403771	1.404430
79	1.405091	1.405752	1.406412	1.407074	1.407735	1.408398	1.409061	1.409723	1.410387	1.411051
80	1.411715	1.412380	1.413044	1.413709	1.414374	1.415040	1.415706	1.416373	1.417039	1.417707
81	1.418374	1.419043	1.419711	1.420380	1.421049	1.421719	1.422390	1.423059	1.423730	1.424400
82	1.425072	1.425744	1.426416	1.427089	1.427761	1.428435	1.429109	1.429782	1.430457	1.431131
83	1.431807	1.432483	1.433158	1.433835	1.434511	1.435188	1.435866	1.436543	1.437222	1.437900
84	1.438579	1.439259	1.439938	1.440619	1.441299	1.441980	1.442661	1.443342	1.444024	1.444705
85	1.445388	1.446071	1.446754	1.447438	1.448121	1.448806	1.449491	1.450175	1.450860	1.451545
86	1.452232	1.452919	1.453605	1.454292	1.454980	1.455668	1.456357	1.457045	1.457735	1.458424
87	1.459114	1.459805	1.460495	1.461186	1.461877	1.462568	1.463260	1.463953	1.464645	1.465338
88	1.466032	1.466726	1.467420	1.468115	1.468810	1.469504	1.470200	1.470896	1.471592	1.472289
89	1.472986	1.473684	1.474381	1.475080	1.475779	1.476477	1.477176	1.477876	1.478575	1.479275

SOLUBILITY OF SUCROSE IN WATER (32).—(Continued)

Solubility								SOLUBILITY OF SUCROSE IN WATER (32)							
°C				°C				°C		% wt.		°C		% wt.	
0	64.18	10	65.58	19	66.93	28	68.37	37	69.89	49	72.06	61	74.38	73	76.85
1	64.31	11	65.73	20	67.09	29	68.53	38	70.06	50	72.25	62	74.58	74	77.06
2	64.45	12	65.88	21	67.25	30	68.70	39	70.24	51	72.44	63	74.78	75	77.27
3	64.59	13	66.03	22	67.41	31	68.87	40	70.42	52	72.63	64	74.98	76	77.48
4	64.73	14	66.18	23	67.57	32	69.04	41	70.60	53	72.82	65	75.18	77	77.70
5	64.87	15	66.33	24	67.73	33	69.21	42	70.78	54	73.01	66	75.38	78	77.92
6	65.01	16	66.48	25	67.89	34	69.38	43	70.96	55	73.20	67	75.59	79	78.14
7	65.15	17	66.63	26	68.05	35	69.55	44	71.14	56	73.39	68	75.80	80	78.36
8	65.29	18	66.78	27	68.21	36	69.72	45	71.32	57	73.58	69	76.01	81	78.58
9	65.43							46	71.50	58	73.78	70	76.22	82	78.80
								47	71.68	59	73.98	71	76.43	83	79.02
								48	71.87	60	74.18	72	76.64	84	79.24



## SOLUBILITY OF SUCROSE IN WATER (32).—(Continued)

°C	% wt.	°C	% wt.	°C	% wt.	°C	% wt.
85	79.46	89	80.38	93	81.30	97	82.25
86	79.69	90	80.61	94	81.53	98	82.49
87	79.92	91	80.84	95	81.77	99	82.73
88	80.15	92	81.07	96	82.01	100	82.97

## FREEZING POINT-SOLUBILITY DATA (64)

System  $C_{12}H_{22}O_{11}$ - $H_2O$ , E = eutectic, m = metastable

°C	g/100 g $H_2O$	°C	g/100 g $H_2O$
Ice		Ice + $C_{12}H_{22}O_{11}$	
± 0.0	0.0	-13.9 E	166.0
-4.03	60.0	$C_{12}H_{22}O_{11}$	
-10.42	130.0	+0.9	180.5
-12.68	150.0	+15.8	196.0
-13.68	164.0	+25.6	210.5
-17.08 m	200.0	+30.5	218.0

## SOLUBILITY OF SUCROSE IN AQUEOUS METHYL ALCOHOL AT 15°C (31)

Vol. % $CH_3OH$ in solvent . . . . .	100	90	80
g sucrose per 100 cm <sup>3</sup> solution . . . . .	0.3	1.6	3.8

## Hydrolysis

## HYDROLYSIS (INVERSION) OF SUCROSE

Sucrose	Acid	°C	k	Lit.
17.1%	0.099N HCl	35	0.00161	(72)
1000 g $H_2O$ + 0.25 g-mole of sucrose + 1 g-mole of acid, 25°C				
$HNO_3$	HCl	$H_2SO_4$	Lit.	
k = 0.00464	0.00500	0.00549	(1)	

## TIME NECESSARY FOR VARYING PERCENTAGES OF HYDROLYSIS (INVERSION) OF SUCROSE WITH HCl (0.01N at 20°C) AS THE CATALYZER (50)

°C	k	50% inver- sion, min	90% inver- sion, min	99.9% inver- sion, hr
50	0.001145	262.9	873.4	43.5
60	0.003806	79.1	262.9	13.1
70	0.01182	25.5	84.6	4.2
80	0.03303	9.11	30.3	1.5
90	0.08922	3.37	11.21	33.4*
100	0.26797	1.12	3.73	11.2*

\* Minutes.

The reaction velocities for lower acidities may be computed without appreciable error by considering the velocity proportional to the concentration of acid. Thus, the velocities at 0.005N HCl will be very closely half those at 0.01N and the time of reaction twice as great.

## REACTION VELOCITIES AT VARIOUS TEMPERATURES

$$k = \frac{1}{t} \log_{10} \frac{r_0 - r}{r_t - r}, t \text{ in min}$$

$$k_{T_2} = k_{T_1} e^x, \text{ where } x = \frac{Q}{R} \frac{T_2 - T_1}{T_2 T_1}$$

Sucrose, 50%; HCl, 0.1N at 20°C.  $Q/R = 12\,925.2$  (48)

°C	k	°C	k
0	0.0000077	59.903	0.04003
15.098	0.000092	69.974	0.1236
30.000	(0.0008732)	80.130	0.3687
39.916	0.00334	90.292	1.033
49.840	(0.01206)	90.316	1.020

Sucrose, 50%; HCl, 0.01N at 20°C.  $Q/R = 12\,940.05$  (48)

°C	k	°C	k
30.00	0.0008148	69.97	0.01194
49.85	0.001122	80.10	0.03429
59.90	0.003766	90.30	0.0939

Sucrose, 60%; HCl, 0.7925N at 20°C.  $Q/R = 13\,087.6$  (48)

°C	k	°C	k
20	0.002156	35.072	0.01882
30.117	0.00983	40.078	0.03780
30.093	0.01001	40.088	0.03791

## INVERSION OF SUCROSE WITH INVERTASE (69)

$$t = \frac{1}{n} \log_{10} \frac{100}{100-p} + 0.002642p - 0.000008860p^2 - 0.0000001034p^3; t = \text{minutes}; p = \% \text{ inversion}; n \text{ is proportional to the amount of active invertase and depends upon the temperature.}$$

Range of invertase concentration from 12 to 1; temperature from 15 to 35°; H-ion concentration  $4 \times 10^{-5}$  to  $3.2 \times 10^{-7}$ .

At any given temperature  $n$  may be used to measure the activity of an invertase solution.

## LENGTH OF TIME REQUIRED TO FORM CARAMEL EQUIVALENT TO 0.01 % INVERT SUGAR (9)

The time, in hours, required to form caramel equivalent to 0.01% invert sugar at any temperature  $t$  (°C) between 39 and 100° may be computed from the equation:

$$\log_{10} \text{hr} = 5.0026 - 0.0595t.$$

## LACTOSE

 $C_{12}H_{22}O_{11}$  (Galactose < Dextrose <)

## TRANSITION TEMPERATURES AND MELTING POINTS (85)

$\alpha$ -hydrate  $\rightarrow$   $\beta$ -anhydrous, 93.5°.  $\alpha$ -anhydrous  $\rightarrow$  liquid, 222.8°.  $\beta$ -anhydrous  $\rightarrow$  liquid, 252.2°.  $\alpha$ -anhydrous is metastable below its melting point.  $\alpha$ -hydrate  $\rightarrow$  liquid, 201.6°.

## Optical Rotation

IN  $H_2O$ 

$[\alpha]_D^{25} = 52.42 + 0.072(20^\circ - t); 5 \text{ g/100 ml (4)}; [\alpha]_{546.1}^{25} = 61.94 + 0.085(20^\circ - t); 5 \text{ g/100 ml (4)}; [\alpha]_D^{20} = 52.53 \text{ (21)}; [\alpha]_{546}^{25} = 61.36; [\alpha]_{589}^{26} = 51.90 \text{ (78)}.$

## ROTATION DISPERSION AT EQUILIBRIUM (30)

Values of  $[\alpha]_D^{20}; C = \text{g hydrate/100 ml}$ 

$\lambda$	$H_2O$ , $C = 2$	Pyridine, $C = 0.5$	Formic acid, $C = 5.9$
656	39.82	31.00	78.64
589	52.42	41.33	97.76
535	62.09	49.66	117.92
508	72.25	60.00	134.38
479	83.25	73.66	160.79
447	98.17	91.66	180.92

 $[\alpha]_D$  IN VARIOUS SOLVENTS

Solvent	Anhy- drous lactose, g/100 ml	°C	$[\alpha]_D^{25}$			$10^3(k_1 + k_2)$	Lit.
			$\alpha$	$\alpha \rightleftharpoons \beta$	$\beta$		
$H_2O$ . . . . .	2.316	14	84.4	55.25		3.78	(60)
Formamide..	2.27	15	82.4	51.2		0.387	(60)
$H_2O$ . . . . .	2.75	17		55.23	35.97	2.97	(60)
Formamide..	1.85	17		51.22	29.11	0.4	(60)
$H_2O$ . . . . .		20	86.		34.5		(38)
$H_2O$ . . . . .		20	90.0	55.3	35.0	4.65	(44)
40%, $C_2H_5OH$ ..		20	81.0	55.3	33.0		(44)
$H_2O$ . . . . .		0				0.5	(35)

 $d[\alpha]_D/dt = -0.08$  between  $t = 10 - 25^\circ C$  (60).

EFFECT OF H<sub>2</sub>SO<sub>4</sub> (11)*N* = normality

<i>N</i> , H <sub>2</sub> SO <sub>4</sub>	0	10	12	14	16	18	20	22	24	26
$[\alpha]_D^{25}$	52.5	56.7	59.0	61.5	63.5	65.5*	68.5	72.5	76.0	99.0

\* Noticeable inversion begins.

## Refractive Index and Density of Aqueous Solutions (77)

% anhydrous lactose	23.38	17.06	11.66	5.80	2.78	1.28
$d_4^{25}$	1.0969	1.0681	1.0448	1.0204	1.0092	1.0018
$n_D^{25}$	1.3716	1.3605	1.3517	1.3423	1.3380	1.3350

## Solubility

## SOLUBILITY IN WATER (38)

*S*<sub>0</sub> = initial, *S*<sub>∞</sub> = final solubility in millimoles of anhydrous lactose per 100 g H<sub>2</sub>O

(a) Solid phase: the hydrate

°C	0.0	15.0	25.0	39.0	49.0	64.0	74.0	89.0
<i>S</i> <sub>∞</sub>	34.8	49.7	63.4	92.7	124.0	193.0	253.0	407.0
<i>S</i> <sub>0</sub>	14.8	20.9	25.3	37.0*	52.0*	77.0*	101.0*	163.0*

(b) Solid phase: β-anhydrous. Final solubility: at 0°, 42.9; at 100°, 61.2 wt. % anhydrous

(c) Solid phase: β-anhydrous

°C	0.0	0.0	100
<i>S</i> <sub>0</sub>	132	(124)	227
<i>S</i> <sub>∞</sub>	220	(extrap.)	461

\* Calculated from final solubility and equilibrium ratio.

## PER CENT β-ANHYDROUS AT EQUILIBRIUM IN A SOLUTION SATURATED WITH THE HYDRATE (38)

°C	0	15	25	39	49	64	74	89
%	5.8	7.7	9.6	14.0	18.0	24.0	27.0	35.0

Per cent hydrate at equilibrium in solution saturated with the β-anhydrous = 17 at 0°C; = 24 at 100°C (38).

SOLUBILITY IN AQUEOUS C<sub>2</sub>H<sub>5</sub>OH (44)g anhydrous lactose in 100 cm<sup>3</sup> 40% C<sub>2</sub>H<sub>5</sub>OH at 20°C = 1.1 initial; = 2.4 final.

## SOLUBILITY AND FREEZING POINT LOWERING

Solubility in H<sub>2</sub>O. Solid phase: lactose hydrate

°C	% lae.	Lit.	°C	% lae.	Lit.	°C	% lae.	Lit.
0	10.6	(39)	57.1	34.9	(28)	100	60.5	(39)
15	14.4	(39)	63.9	39.1	(28)	107.0	63.9	(28)
21.5	16.7	(79)	64.0	39.7	(39)	121.5	69.4	(28)
25	17.8	(39)	73.5	45.8	(28)	133.6	73.2	(28)
28	19.4	(79)	74.0	46.2	(39)	138.8	75.2	(28)
38	23.5	(79)	79.1	49.6	(28)	158.8	81.1	(28)
39	24.0	(39)	87.2	55.1	(28)	178.8	86.7	(28)
49	29.7	(39)	88.2	56.0	(28)	200	92.5	(27)

## FREEZING POINT LOWERING (38, 58)

Between 1 and 30 millimoles lactose per 100 g H<sub>2</sub>O the molal lowering is 1.86°/mole and at 48 millimoles 1.89°/mole.*Cryohydrate Points.*—Initial, −0.279° and 14.8 millimoles per 100 g H<sub>2</sub>O; final for hydrate, −0.65°; initial for β-anhydrous, −2.3°; final for β-anhydrous, −4.1°.

## Mutarotation

MUTAROTATION IN H<sub>2</sub>O

°C	0.0	15.0	25.0	0	14.0	17.0	20.0
10 <sup>3</sup> ( <i>k</i> <sub>1</sub> + <i>k</i> <sub>2</sub> )	0.51	2.97	7.92		3.78	2.97	6.2
10 <sup>3</sup> <i>k</i> <sub>1</sub>	0.29	1.55	4.65	0.24			
10 <sup>3</sup> <i>k</i> <sub>2</sub>	0.21	1.08	3.08				
Lit.	(35)	(35)	(35)	(38)	(60)	(60)	(11)

## COMPOSITION OF AN AQUEOUS SOLUTION AT EQUILIBRIUM (27)

°C	0	25	50	75	92	100
% β / % α	1.65	1.58	1.51	1.45	1.39	1.33

## Hydrolysis (10)

$$k_H = \frac{1}{t} \log_{10} \frac{r_0 - r_\infty}{r_t - r_\infty} \quad t \text{ in min}$$

Anhydrous lactose, g/l	Acid	10 <sup>3</sup> <i>k</i> <sub>H</sub>	°C
50	22 <i>N</i> H <sub>2</sub> SO <sub>4</sub>	4.4	20
50	24 <i>N</i> H <sub>2</sub> SO <sub>4</sub>	7.7	20
80	HCl, <i>d</i> = 1.185	1.1	15
80	HCl, <i>d</i> = 1.185	2.1	20
80	HCl, <i>d</i> = 1.185	4.3	25
80	HCl, <i>d</i> = 1.185	8.2	30
80	HCl, <i>d</i> = 1.185	17.1	35
80	HCl, <i>d</i> = 1.185	35.2	40
40	HCl, <i>d</i> = 1.185	5.1	25
120	HCl, <i>d</i> = 1.185	3.4	25
200	HCl, <i>d</i> = 1.185	1.5	25
80	HClO <sub>4</sub> , <i>d</i> = 1.67	24.2	20
	HClO <sub>4</sub> , <i>d</i> = 1.67	50.0	25

C<sub>12</sub>H<sub>22</sub>O<sub>11</sub>, MALTOSE

Composition: (Glucose &lt; Glucose &lt;)

## Optical Rotation

IN H<sub>2</sub>O (21) $[\alpha]_D^{20} = 138.475 - 0.01837p$  for values of *p* from 5 to 35 wt. % in vacuo.  $[\alpha]_{546}^{25} = 153.75$ .  $[\alpha]_{589}^{25} = 131.25$  (78).

## IN VARIOUS SOLVENTS AT 20°C

Solvent	Maltose, g/100 ml	$[\alpha]_D^{20}$	10 <sup>3</sup> ( <i>k</i> <sub>1</sub> + <i>k</i> <sub>2</sub> )	Lit.
H <sub>2</sub> O		168*	136.0	118.0
60% C <sub>2</sub> H <sub>5</sub> O H		158*	128.1	111.0
H <sub>2</sub> O	2.52		136.2	123
Formamide	2.12		130.3	113
H <sub>2</sub> O			137	119
H <sub>2</sub> O			137	
Pyridine			122.0	
H <sub>2</sub> O			137	
Pyridine			124	
Formic acid			175	

\* Calculated.

## EFFECT OF PYRIDINE

Two g maltose in 200 cm<sup>3</sup> of a 5% aqueous pyridine solution (34)

After, days	0	1	2	After heating for, hr	0	0.5	1.5
<i>R</i> , °are	6.75	6.70	6.70	<i>R</i> , °are	6.7	5.6	4.8

EFFECT OF H<sub>2</sub>SO<sub>4</sub>

Maltose 5 g/100 ml (11)

<i>N</i> of H <sub>2</sub> SO <sub>4</sub>	0	10	12	18	22
$[\alpha]_D^{25}$	135.5	129.0	127.5	129.5	132.0



## EQUILIBRIUM ROTATION

Values of  $[\alpha]_D^{20}$  for  $\alpha \rightleftharpoons \beta$  in various solvents; maltose < 5 g/100 ml (30)

$\lambda$ , m $\mu$ .....	656	589	535	508	479	447
H <sub>2</sub> O.....	111	137	167	180	229	236
Pyridine.....	100	124	152	180	212	231
Formic acid.....	140	175	210	248	292	320

## Refractive Index and Density of Aqueous Solutions (77)

% anhydrous maltose.....	19.40	9.60	4.77	2.32	1.16
$d_4^{25}$ .....	1.0777	1.0362	1.0160	1.0064	1.0017
$n_D^{25}$ .....	1.3639	1.3482	1.3406	1.3368	1.3354

Solubility  
IN H<sub>2</sub>O (29)

°C	0.6	21.0	29.6	34.4	43.5	49.4
% M.	36.1	44.1	48.0	49.6	55.3	58.3
°C	54.2	59.8	66.3	74.2	87.0	96.5
% M.	60.2	63.7	66.7	72.3	79.3	85.1

IN 60% C<sub>2</sub>H<sub>5</sub>OH AT 20°C (44)

Initial, 3.0; final 4.75, g/100 cm<sup>3</sup> of solution. Equilibrium mixture contains 64%  $\beta$  and 36%  $\alpha$ .

## FREEZING POINT LOWERING (29)

In H <sub>2</sub> O	% anhydrous maltose....	24.0	16.7	12.4	7.16(58)
	$\Delta t_F$ , °C.....	1.87	1.16	0.79	0.395
In 0.1N NH <sub>4</sub> OH	% anhydrous maltose	25.1	18.3	28.9	16.9
aq. soln.	$\Delta t_F$ , °C.....	1.94	1.25	2.44	1.17

C<sub>6</sub>H<sub>12</sub>O<sub>6</sub>, DEXTROSE (*d*-Glucose)

## Optical Rotation

The saccharimetric normal weight for dextrose is 32.231 g (in air,  $d = 0.0012$ , brass weights) (47).

ROTATIONS FOR  $\lambda = 546.1$  m $\mu$ , 20°C; 200 MM TUBE; AQUEOUS SOLUTION

Saccharimetric normality...	1	$\frac{4}{5}$	$\frac{3}{5}$	$\frac{2}{5}$	$\frac{1}{5}$
$R$ , °arc.....	40.897	32.5745	24.328	16.142	8.042

## CORRECTIONS TO BE ADDED TO SACCHARIMETRIC READINGS OF DEXTROSE SOLUTIONS (47)

°S	Corr.	°S	Corr.	°S	Corr.
100	0	65	0.50	30	0.46
95	0.10	60	0.52	25	0.41
90	0.20	55	0.54	20	0.35
85	0.28	50	0.55	15	0.28
80	0.35	45	0.54	10	0.20
75	0.41	40	0.53	5	0.10
70	0.46	35	0.50	2	0.05

SPECIFIC ROTATORY POWER IN H<sub>2</sub>O

$[\alpha]_{546.1}^{20} = 62.032 + 0.04257 C$ ;  $= 62.032 + 0.0422 p + 0.0001897 p^2$ . Valid from  $C = 6$  to 32 g/100 ml soln.  $p =$  wt. %. All weights *in vacuo* (47).  $[\alpha]_D^{20} = 52.50 + 0.0188p + 0.000517p^2$ . Valid from  $p = 0$  to 35 wt. %. All weights *in vacuo* (21, 89).  $[\alpha]_{546}^{25} = 62.02$ ;  $[\alpha]_{589}^{25} = 52.48$  (78).

IN WATER, IN PYRIDINE AND IN FORMIC ACID  
Values of  $[\alpha]_D^{20}$  (30)

$\lambda$	In H <sub>2</sub> O, $\frac{1}{4}$ to $\frac{1}{32}$ N	In pyridine, $\frac{1}{4}$ N	In formic acid
656	41.47	60.87	96.0
589	52.52	75.64	122.8
535	64.90	93.55	150.0
508	73.03	104.00	176
479	83.05	118.02	203
447	95.79	136.90	224

## IN VARIOUS SOLVENTS AT 20°C

Solvent	Dextrose, g/100 ml	$[\alpha]_D^{20}$			$10^3 (k_1 + k_2)$	Lit.
		$\alpha$	$\alpha \rightleftharpoons \beta$	$\beta$		
H <sub>2</sub> O.....	9.1	108.5	52.2		6.27	(60)
Formamide.....	2.5	122.7	57.27		1.09	(60)
H <sub>2</sub> O.....	2.3		52.02	20.76	6.9	(61)
Formamide.....	1.7		56.28	15.74	0.996	(61)
H <sub>2</sub> O.....		113.4	52.2	19.7		(44)
80% C <sub>2</sub> H <sub>5</sub> OH.....		115.2	59.0	20.3		(44)
C <sub>2</sub> H <sub>5</sub> OH.....		121.5	70.45	16.5		(44)
Pyridine.....			75.56			(30)
Formic acid.....			122.8			(30)

## EFFECT OF PROPYL ALCOHOL

Alcohol used had  $d_4^{19} = 0.810$ . Dextrose concn. < 50 g/l (26)

Alc., g/l.....	100	200	300	400	500	600	700
$[\alpha]_D^{19}$ .....	52.20	52.81	53.22	53.48	55.35	55.44	56.81

## EFFECT OF SALTS(66)

Salt	$[\alpha]_D^{20}$	Salt	$[\alpha]_D^{20}$
Nil.....	52.8	2N NH <sub>4</sub> Cl.....	52.3
4N KI.....	47.4	2N CH <sub>3</sub> COONH <sub>4</sub> .....	52.3
4N KBr.....	48.5	N CH <sub>3</sub> COOK.....	52.3
4N KCl.....	49.6	4N MgCl <sub>2</sub> .....	52.8
4N NH <sub>4</sub> NO <sub>3</sub> .....	50.6	N MgCl <sub>2</sub> .....	52.8
2N KNO <sub>3</sub> .....	50.6	2N MgSO <sub>4</sub> .....	52.8
4N NH <sub>4</sub> Cl.....	51.2	2N CH <sub>3</sub> COONa.....	52.8
2N KCl.....	51.2	N CH <sub>3</sub> COONa.....	52.8
N K <sub>2</sub> SO <sub>4</sub> .....	51.2	N CH <sub>3</sub> COONH <sub>4</sub> .....	52.8
2N (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> .....	51.7	2N BaCl <sub>2</sub> .....	54.7
2N CH <sub>3</sub> COOK.....	51.7	3N BaCl <sub>2</sub> .....	55.5
4N NaNO <sub>3</sub> .....	52.3	2N CaCl <sub>2</sub> .....	56.0
2N Na <sub>2</sub> SO <sub>4</sub> .....	52.3	4N CaCl <sub>2</sub> .....	61.2

## EFFECT OF HCL (97)

## Dextrose concn., 5 g/100 ml

% HCl.....	3.65	19.25	30.4	34.4	37.6	39.9	41.4	44.5
$[\alpha]_D^{16-17}$ .....	+54.5	57.2	61.0	67.0	82.5	97.5	106.0	164.6

% HCl.....	0	42.0	46.6	46.7
°C.....	8	8	-12	-12
$[\alpha]_D^{16}$ .....	52.2	113.3	200.0	202.0

EFFECT OF H<sub>2</sub>SO<sub>4</sub> (11)

Dextrose concn. = 50 g/l at 25°. The table gives values of  $[\alpha]_D^{25}$  in acid of the normality stated. In acid above 22N, mutarotation is found. At 20°, 50 g/l in 24N acid gives  $k = 0.0020$ .

0	10N	16N	18N	20N	22N	24N	26N	28N
52.8	56.0	62.5	65.0	67.5	72.5	80.0	91.0	107.0

## Refractive Index and Density of Aqueous Solutions (77)

% wt.....	24.03	20.14	15.72	10.20	4.36	2.11	1.00
$d_4^{25}$ .....	1.0962	1.0795	1.0604	1.0370	1.0146	1.0051	1.0007
$n_D^{25}$ .....	1.3710	1.3646	1.3575	1.3486	1.3401	1.3366	1.3351

## DENSITY OF AQUEOUS SOLUTIONS (47)

$d_4^{20} = 0.99840 + 0.003788 p + 0.00001412 p^2$ . Range of  $p$ , 4 to 30, wt. % dextrose. All weights *in vacuo*.

## Solubility

## SYSTEM: DEXTROSE-WATER (49); v. FIG. 2

The solid curves show the final equilibria with respect to the solid phases, ice, dextrose hydrate, and anhydrous dextrose. The dotted curve shows the instantaneous solubility before mutarotation. All data are expressed in terms of anhydrous dextrose.

SYSTEM: DEXTROSE-ETHYL ALCOHOL-(WATER), 20°C  
 $S_i$  (resp.  $S_\infty$ ) = initial (resp. final) solubility, g anhyd. dextrose per liter of solution (44)

% wt., $C_2H_5OH$	$\alpha$ -anhydrous		$\alpha$ -hydrate		$\beta$ -anhydrous	
	$S_0$	$S_\infty$	$S_0$	$S$	$S_0$	$S_\infty$
80	20	45	13	30	49	91
100	8.5	16				

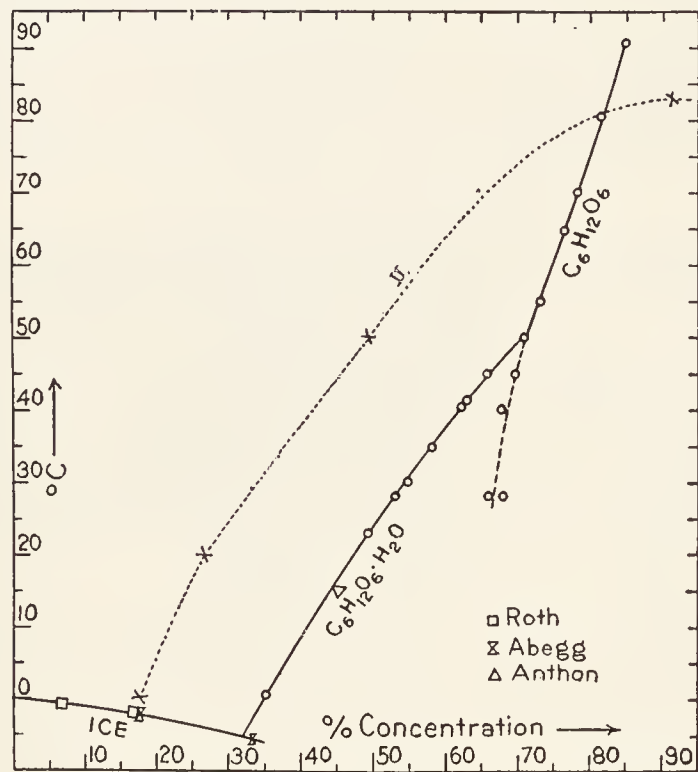


Fig. 2.

Mutarotation

MUTAROTATION AT 20°C (24)

$B$  = moles buffer per l solution

pH	$10^3 (k_1 + k_2)$	pH	$10^3 (k_1 + k_2)$	pH	$10^3 (k_1 + k_2)$	pH	$10^3 (k_1 + k_2)$
$B = 0.1$		$B = 0.1$		$B = 0.01$		$B = 0.05$	
4.88	13.0	3.08	7.7	4.96	7.28	4.87	10.7
4.28	9.0	2.66	8.1	3.43	6.74	$B = 0.2$	
4.08	8.7	2.04	9.5	2.54	7.20	4.80	17.9
3.44	7.8	1.02	20.0	1.75	8.72	$B = 0$	
						4.93	7.22

VARIATION OF pH WITH TEMPERATURE AND CONCENTRATION OF DEXTROSE (68)

$[\alpha]_D = +111.2$  for  $\alpha$ -form;  $= +17.5$  for  $\beta$ -form;  $= 52.5$  for equilibrium mixture; at all temperatures and concentrations used

pH	$10^3 (k_1 + k_2)$	pH	$10^3 (k_1 + k_2)$	pH	$10^3 (k_1 + k_2)$	pH	$10^3 (k_1 + k_2)$
$\alpha$ -form, 0.15°C		37°C		6.50	34.3	6.43	0.78
1.33	2.42	1.0	118.6	6.55	33.0	6.70	0.80
2.38	0.91	1.72	50.0	6.75	51.7	7.51	1.86
3.05	0.79	2.06	37.6	7.27	86.7	8.00	3.30
3.98	0.79	2.53	32.6	7.55	118.1	37°C	
5.07	0.77	2.73	32.0	8.50	220.5	1.72	48.6
5.35	0.77	3.36	30.0	$\beta$ -form, 0.15°C		2.60	31.3
6.84	0.92	3.99	29.9	1.33	2.10	2.92	30.0
7.51	2.2	5.58	30.5	2.02	0.93	4.82	30.0
		5.95	29.8	4.80	0.78	5.90	30.4
		6.37	32.2	6.00	0.76	6.30	32.5

$k_1 + k_2 = 0.0096 + 0.258[H^+] + 9750[OH^-]$ at 25° (36)									
HCl, m/l. . . . .	0.0	0.001	0.005	0.01	0.03	0.06	0.10	$t, ^\circ C$	
$10^3 (k_1 + k_2)$ . . . . .	10.6	9.8	11.2	12.1	16.9	25.3	35.4	24.7	
$k_1 + k_2 = 0.0167 + 0.44[H^+]$ at 30° in HCl solutions (37)									
HCl, m/l. . . . .	0.0	0.0 + invertase	0.5	0.10	0.20				
$10^3 (k_1 + k_2)$ . . . . .	16.7	16.7	38.3	62.0	10.5				

MUTAROTATION AT 5.4°C (25)

Minimum rate occurs at pH = 5.0 which corresponds to a dissociation constant for dextrose of  $5 \times 10^{-18}$ . An average value for  $Q$  is 17 500

Form	Reagent	pH	$10^3 (k_1 + k_2)$
$\alpha$	1.3N HCl. . . . .	-0.08	108.6
$\beta$	1.3N HCl. . . . .	-0.06	107.2
$\alpha$	0.3N HCl. . . . .	+0.54	14.38
$\alpha$	0.1N HCl. . . . .	1.05	4.35
$\beta$	0.1N HCl. . . . .	1.06	4.14
$\alpha$	0.03N HCl. . . . .	1.52	2.26
$\alpha$	0.01N HCl. . . . .	1.98	1.61
$\beta$	0.01N HCl. . . . .	1.99	1.55
$\alpha$	0.002N HCl. . . . .	2.74	1.38
$\beta$	0.045N HCl. . . . .	5.13	1.19
$\alpha$	0.001N $NaHCO_3$ . . . . .	7.34	1.33
$\beta$	0.003N $NaHCO_3$ . . . . .	7.84	1.46
$\alpha$	0.01N $NaHCO_3$ . . . . .	8.14	1.56
$\beta$	0.01N $NaHCO_3$ . . . . .	8.25	1.90
$\beta$	0.0015N $Na_2CO_3$ . . . . .	9.13	7.82
$\alpha$	0.003N $Na_2CO_3$ . . . . .	9.41	12.48
$\alpha$	0.01N $Na_2CO_3$ . . . . .	10.07	41.10
$\beta$	0.01N $Na_2CO_3$ . . . . .	10.11	41.75
$\alpha$	0.003N NaOH. . . . .	10.41	83.76

VARIATION WITH CONCENTRATION AND TEMPERATURE. AQUEOUS SOLUTIONS (42)

g/100 ml	$10^3 (k_1 + k_2)$ 25°C	Dextrose < 100 g/l	
3	10.50	$^\circ C$	$10^3 (k_1 + k_2)$
3	10.57		$\alpha$ $\beta$
3	10.68	0.7	0.74    0.74
6	10.48	5	1.29    1.50
9.6	10.59	10	2.25    2.23
16	11.04	15	3.99    3.79
25	11.35	20	6.35    6.54
32	10.68	25	10.50    10.57
37	10.60	30	1.75    1.68
52	10.08	40	4.37    3.95
64	9.31		

$\log_{10} (k_1 + k_2) = 11.0198 - 3873/T.$

MUTAROTATION IN METHYL ALCOHOL (5)

Concentration dextrose ca. 12.3 g/l

$CH_3OH$		$CH_3OH + 0.5\% H_2O$		$CH_3OH + 1\% H_2O$		$CH_3OH + 2\% H_2O$	
Time, hr	$[\alpha]_D^{44.8}$	Time, hr	$[\alpha]_D^{44.8}$	Time, hr	$[\alpha]_D^{44.8}$	Time, hr	$[\alpha]_D^{44.8}$
0.25	111.2	0.28	111.5	0.28	109.6	0.28	110.9
.43	110.0	.72	105.2	.53	106.9	.52	107.5
.83	106.3	1.32	102.4	.88	104.3	.77	105.2
1.38	104.8	1.63	98.5	1.47	99.2	1.13	99.9
2.63	97.7	2.22	96.9	1.92	95.9	1.82	90.1
4.05	88.4	3.22	91.0	3.22	85.8	2.33	85.9
5.53	83.2	4.00	86.9	4.33	81.7	3.42	79.5
6.83	79.5	5.85	80.5	5.88	74.8	4.22	76.9
		6.92	76.8	8.08	69.7	5.38	72.6
		8.38	73.1	11.42	66.7	6.75	69.7



## MUTAROTATION IN METHYL ALCOHOL (5).—(Continued)

CH <sub>3</sub> OH		CH <sub>3</sub> OH + 0.5% H <sub>2</sub> O		CH <sub>3</sub> OH + 1% H <sub>2</sub> O		CH <sub>3</sub> OH + 2% H <sub>2</sub> O	
Time, hr	$[\alpha]_D^{44.8}$	Time, hr	$[\alpha]_D^{44.8}$	Time, hr	$[\alpha]_D^{44.8}$	Time, hr	$[\alpha]_D^{44.8}$
		12.05	69.9	24.0	64.0	8.93	66.1
		23.18	64.5			11.58	64.1
		25.08	64.5			24.25	64.1

## MUTAROTATION IN ETHYL ALCOHOL OF VARYING CONCENTRATIONS AT 20°C (44)

% C <sub>2</sub> H <sub>5</sub> OH.....	0	20	40	60	70	80
10 <sup>3</sup> (k <sub>1</sub> + k <sub>2</sub> ).....	6.5	4.8	3.0	1.82	1.56	1.14

C<sub>6</sub>H<sub>12</sub>O<sub>6</sub>, LEVULOSE

## Optical Rotation

## IN WATER (90)

$[\alpha]_D^{25} = -(88.50 + 0.145p)$ ;  $-(88.50 + 0.150 C - 0.00086 C^2)$ , from  $p = 2.6$  to 18.6 wt. % and from  $C = 2.6$  to 20 g/100 ml.  $[\alpha]_D^t = [\alpha]_D^{25} + (0.566 + 0.0028C)(t^\circ - 25^\circ)$ ; from 15 to 37°C.  $[\alpha]_{589}^{20}/[\alpha]_{589}^{20} = 0.8467$ .  $[\alpha]_D^{20} = -(88.16 + 0.258p)$  (21).  $[\alpha]_{546}^{25} = -105.30$ ;  $[\alpha]_{589}^{25} = -89.40$  (78).

IN WATER, IN PYRIDINE AND IN FORMIC ACID AT 20°  
Values of  $-\alpha_\lambda^{20}$  for different concentrations (C) of levulose (30)

$\lambda$	In H <sub>2</sub> O				In pyridine			
	$\frac{1}{4}N$	$\frac{1}{8}N$	$\frac{1}{16}N$	$\frac{1}{32}N$	$\frac{1}{4}N$	$\frac{1}{8}N$	$\frac{1}{16}N$	$\frac{1}{32}N$
656	76.39	75.30	74.86	74.04	26.44	25.81	25.39	24.77
589	90.46	89.96	88.36	87.49	35.48	35.26	34.96	34.51
535	107.21	106.66	105.70	104.84	42.59	42.22	41.71	41.24
508	136.85	135.8	133.35	130.12	49.10	48.77	48.36	47.62
479	151.11	149.27	147.20	146.20	56.0	55.37	54.78	54.07
447	166.55	163.88	160.49	158.10	63.93	62.70	62.11	61.33

Formic acid, C = 8.6	$\lambda$	656	589	535	508	479	447
g/100 ml	$[\alpha]_\lambda^{20}$	37.25	46.77	52.83	64.66	75.54	85.84

Pyridine, C = 1.8	°C	22	35	45
g/100 ml	$[\alpha]_{556}^t$	26.38	24.44	22.77

## IN AQUEOUS ETHYL ALCOHOL (2)

Composition: 2 moles levulose + 100 moles H<sub>2</sub>O +  $x$  moles C<sub>2</sub>H<sub>5</sub>OH. Values of  $[\alpha]_\lambda^{25}$

$x$	$\lambda$	578 (HgY)	546 (HgG)	436 (HgB)
0		-93.73	-106.03	-175.29
9.28		-87.08	-98.55	-162.65
24.65		-80.13	-90.69	-149.62
54.9		-73.50	-83.17	-137.48
167.0		-64.22	-72.52	-120.59
1724.0		-49.7	-55.7	-93.7

## IN VARIOUS SOLVENTS

Solvent	Levulose, g/100 ml	$[\alpha]_D^{20}$			10 <sup>3</sup> (k <sub>1</sub> + k <sub>2</sub> )	Lit.
		$\alpha^*$	$\alpha \rightleftharpoons \beta$	$\beta$		
Formamide.....	2.26		-109.51	-151.76	8.39	(60)
H <sub>2</sub> O.....	10		-92.0	-133.5		(44)
80% C <sub>2</sub> H <sub>5</sub> OH.....	10	-7	-68.6	-133.5		(44)
95% C <sub>2</sub> H <sub>5</sub> OH....		0	-52.5	-122		(44)
CH <sub>3</sub> OH.....		-8	-61.4	-122		(44)

## IN VARIOUS SOLVENTS.—(Continued)

Solvent	Levulose, g/100 ml	$[\alpha]_D^{20}$			10 <sup>3</sup> (k <sub>1</sub> + k <sub>2</sub> )	Lit.
		$\alpha^*$	$\alpha \rightleftharpoons \beta$	$\beta$		
80% C <sub>2</sub> H <sub>5</sub> OH....					9.1†	(44)
H <sub>2</sub> O.....	$\frac{1}{4}N$		-90.5			(30)
Pyridine.....	$\frac{1}{4}N$		-35.5			(30)
Formic acid.....	5 to 8		-53.0			(30)
	$t, ^\circ C$		$[\alpha]_{546}^t$			
H <sub>2</sub> O.....	14.3	9.942	-115.7	-161	65	(71)
H <sub>2</sub> O.....	0.0	4.9	-123.6	-155	17	(71)
Aq., C <sub>2</sub> H <sub>5</sub> OH						
$d_4^{14} = 0.930$	15.3	10.06	-96.4	-156	22	(71)
$d_4^{15} = 0.876$	0.0	4.9	-96.1	-154	1	(71)

\* Computed from solubilities and  $[\alpha]_D$  for  $\beta$ -form. †  $k_1 = 0.0047$ .

EFFECT OF HCL IN H<sub>2</sub>O (97)

% HCl.....	0	25	37.6	40.0	42.0
°C.....	9	8	8	8	8
$[\alpha]_D^t$ .....	-95.1	-116	-133	-154	-180

## Solubility

In H <sub>2</sub> O (51)	°C	20	25	30	35	40	45	50	55
	% levulose	78.94	80.29	81.64	82.98	84.34	85.64	86.90	88.10

Solvent	g/100 ml solution		Composition, at equilibrium	Lit.
	Initial	Final		
80% C <sub>2</sub> H <sub>5</sub> OH.....	13.4	27.4	48% $\beta$ , 51% $\alpha$	(44)
95% C <sub>2</sub> H <sub>5</sub> OH.....	1.8	4.2	43% $\beta$ , 57% $\alpha$	(44)
CH <sub>3</sub> OH.....	5.2	11.1	47% $\beta$ , 53% $\alpha$	(44)

## Mutarotation

## WITH HCL AT 30°C (37)

HCl, mole/l.....	0	0.0005	0.0010	0.0040	0.0100
10 <sup>3</sup> (k <sub>1</sub> + k <sub>2</sub> ).....	186	140	128	130	196

## EFFECT OF pH AND TEMPERATURE (68)

0.15°C		15°C		25°C		37°C	
pH	10 <sup>3</sup> (k <sub>1</sub> + k <sub>2</sub> )	pH	10 <sup>3</sup> (k <sub>1</sub> + k <sub>2</sub> )	pH	10 <sup>3</sup> (k <sub>1</sub> + k <sub>2</sub> )	pH	10 <sup>3</sup> (k <sub>1</sub> + k <sub>2</sub> )
1.33	101.0	2.5	64.7	2.5	118.9	1.70	460
2.48	16.2	3.3	36.8	3.4	86.0	2.06	350
3.17	8.5	5.1	41.5	5.1	99.2	3.36	195
5.07	8.7	5.8	53.5	5.7	107.6	4.62	205
6.00	10.4	6.3	64.7	6.4	156.1	5.10	236
6.28	17.8					6.10	275
						7.67	741

°C		0.15	15	25	37
$[\alpha]_D^t$ initial.....		-130.8	-130.8	-130.8	-130.8
$[\alpha]_D^t$ final.....		-100	-94	-88	-81

## EFFECT OF BORIC ACID (12)

Levulose, 1 molal, 0°C	H <sub>3</sub> BO <sub>3</sub> , m/l	0.22 molal	0.11 molal	0
	10 <sup>3</sup> (k <sub>1</sub> + k <sub>2</sub> )	40	39	12.4

VELOCITY OF CONVERSION OF ARTICHOKE JUICES UNDER VARYING  
CONDITIONS OF ACIDITY AND TEMPERATURE (51)

$$k = \frac{1}{t} \log_{10} \frac{R_0 - R_\infty}{R_t - R_\infty}$$

$R_0$ , initial rotation;  $R_\infty$ , rotation at completion of conversion

	$t, ^\circ\text{C}$	Acidity (apparent) normality	$k$
$R_0 = +0.08$ , $R_\infty = -26.43$	79.8	0.10 $\text{H}_2\text{SO}_4$	0.0137
	79.8	.20 $\text{H}_2\text{SO}_4$	.0788
	78.2	.10 $\text{HCl}$	.0381
$R_0 = -2.40$ , $R_\infty = -25.88$	99.0	0.0294 $\text{HCl}$	0.00327
	99.0	.0516 $\text{HCl}$	.02737
	99.0	.0667 $\text{HCl}$	.1371
$R_0 = -1.29$ , $R_\infty = -34.48$	99.0	0.0240 $\text{HCl}$	0.0010
	99.0	.0462 $\text{HCl}$	.00593
	99.0	.0571 $\text{HCl}$	.0163
	99.0	.0676 $\text{HCl}$	.0353
	99.0	.0773 $\text{HCl}$	.0707
	99.0	.1041 $\text{HCl}$	.3172

The "apparent" acidities are those which would have been produced in pure water. A portion of the acid in each instance was rendered ineffective by inorganic impurities.

VELOCITY OF CONVERSION OF INULIN IN THE PRESENCE OF VARYING  
CONCENTRATIONS OF HYDROCHLORIC ACID AT  $100^\circ\text{C}$

Normality of $\text{HCl}$	Velocity constant, $k$	$k$ (ash-free) in 0.01N $\text{HCl}$
0.0095	0.00641	$\left\{ \begin{array}{l} k(3-2) = 0.0184 \\ N(3-2) \end{array} \right.$
0.0199	.0394	$\left\{ \begin{array}{l} k(4-3) = 0.0212 \\ N(4-3) \end{array} \right.$
0.0545	.1022	$\left\{ \begin{array}{l} k(4-2) = 0.0199 \\ N(4-2) \end{array} \right.$
0.1034	.2057	
Mean.....		0.020

By taking the differences in velocity at the higher acidities the neutralizing action of inorganic impurities is arithmetically eliminated.

DECOMPOSITION OF LEVULOSE IN THE PRESENCE OF  
SULFURIC ACID(51)

$t, ^\circ\text{C}$	Time in min	Acidity normality	Polarization in saccharimeter deg.
			86.25*
100	15	0.0304	83.70
100	30	.0304	82.90
100	15	.0584	83.30
100	30	.0584	81.16
			85.89*
70	15	.0474	85.87
70	30	.0474	85.63
70	15	.0891	85.79
70	30	.0891	85.26

\* Control solution.

INVERT SUGAR

Mixture of equal parts of dextrose and levulose obtained by hydrolysis of sucrose.

Optical Rotation

IN  $\text{H}_2\text{O}$

$[\alpha]_D^{20} = -19.447 - 0.06068p + 0.000221p^2$  between  $p = 9$  and 68 wt. %. All weights in *vacuo* (21).  $[\alpha]_{546}^{25} = -21.50$ .  $[\alpha]_{689}^{25} = -18.39$  (78).

EFFECT OF VARIOUS SUBSTANCES ON THE ROTATION

$R$  (in  $^\circ\text{S}$ ) =  $-42.00^\circ - 10^{-3} am$ , where  $m$  = g anhyd. reagent per 100 ml of solution and  $R$  is twice the rotation (in  $^\circ\text{S}$ ) observed with 13 g of inverted sucrose per 100 ml.  $\text{Ac} = \text{C}_2\text{H}_3\text{O}_2$  (48).

Reagent	$\text{HCl}$	$\text{NaCl}$	$\text{NH}_4\text{Cl}$	$\text{CaCl}_2$	$\text{K}_2\text{C}_2\text{O}_4$	$\text{HAc}$	$\text{H}_3\text{PO}_4$
$a$ .....	540.7	540	563	710	510	82.3	77.6
For $m \gg$ .....	9.3	3.7	3.7	7.5	12.9	41	5.5

Reagent	$x\text{PbAc}_2 \cdot y\text{PbO}$	$\text{PbAc}$	$\text{NH}_4\text{NO}_2$	$\text{KCl}$	$\text{Na}_2\text{HPO}_4$ 12 aq.	$\text{NaAc}$ 3 aq.
$a$ .....	-1430	20	399	486	161	189
At $m = ..$	2.57	3.03	2.68	11.8	12.26	12.85

Decomposition in the Presence of  $\text{HCl}$ , 0.7925N (48)

50°C	Min	0	38	78	128	235		
	°S	33.25	33.04	32.95	32.80	32.44		
60°C	Min	0	8	18	33	48	63	93
	°S	33.25	33.11	32.93	32.76	32.60	32.31	32.02
70°C	Min	0	4	8	12	17	22	32
	°S	33.25	33.00	32.62	32.46	32.26	31.89	31.45
80°C	Min	0	3	6	10	14	19	
	°S	33.25	32.61	32.00	31.30	30.82	30.07	

$\text{C}_6\text{H}_{12}\text{O}_6$ , MANNOSE

Optical Rotation

IN  $\text{H}_2\text{O}$

$C$  = g anhyd. mannose per 100  $\text{cm}^3$  solution at  $20^\circ\text{C}$  (44)

$C$ .....	3.25	4.53	10.2	16.9	20.55
$[\alpha]_{\text{D}}^{20}$ .....	14.6	14.5	14.1	13.6	13.4

$C$ .....	30.15	39.7	50	60	70	80
$[\alpha]_{\text{D}}^{20}$ .....	13.1	12.8	12.3	11.9	11.4	10.9

IN VARIOUS SOLVENTS

Solvent	Mannose, g/100 ml	$^\circ\text{C}$	$[\alpha]_D^{20}$			Lit.
			$\alpha$	$\alpha \rightleftharpoons \beta$	$\beta$	
$\text{H}_2\text{O}$ .....	2.8	19		+14.40	-19.9	(61)
Formamide.....	2.0	20		11.84	-26.9	(61)
$\text{H}_2\text{O}$ .....		20	+34*	14.6	-17.	(44)
80% $\text{C}_2\text{H}_5\text{OH}$ .....		20	+34*	25.7	-14.9	(44)
$\text{CH}_3\text{OH}$ .....		20	39*	30.1	-16.5	(44)
$\text{H}_2\text{O}$ .....		20	30			(56)
80% $\text{C}_2\text{H}_5\text{OH}$ .....		20	35			(56)

\* Computed from initial and final solubilities and rotations of the  $\beta$ -form.

EFFECT OF  $\text{HCl}$  ON  $d$ -MANNOSE

$\text{Ca. 5 g anhyd. mannose per 100 ml solution}$  (97)

% $\text{HCl}$ .....	0	8	25	31	37.6	40.0	42.0
$^\circ\text{C}$ .....	13	10	10	10	10	10	10
$[\alpha]_D^{15}$ .....	+14.1	+10.5	+4.0	+3.0	+13.3	+31.3	+54.6

EFFECT OF  $\text{H}_2\text{SO}_4$

1.25 g anhyd. mannose in 25  $\text{cm}^3$ ;  $\text{H}_2\text{SO}_4 = 24N$ ;  $25^\circ\text{C}$  (11)

$t$ , min.....	5	10	20	30	60	120	240	360
$\alpha$ , $^\circ\text{arc}$ .....	-8.3	-8.3	-7.5	-6.7	-5.0	-1.8	$\pm 0.0$	$\pm 2.5$



## Solubility

Solid phase:  $\beta$ -mannose; 20°C; g/100 cm<sup>3</sup> solution (44)

Solvent	Initial	Final	$\alpha \rightleftharpoons \beta$ mix.	
100% CH <sub>3</sub> OH.....	0.78	4.4	% $\alpha$	% $\beta$
80% C <sub>2</sub> H <sub>5</sub> OH.....	2.4	13.0	82	18

## Mutarotation

IN H<sub>2</sub>O $C$  = g mannose per 100 cm<sup>3</sup> of solution; 19.7°C (43)

$C$ .....	5.13	8.0	10.0	10.2	19.1	24.7
$10^3(k_1 + k_2)$ .....	17.7	17.9	17.5	17.8	18.1	19.1
$C$ .....	27.1	36.8	45.0	50.0	52.0	56.0
$10^3(k_1 + k_2)$ .....	19.2	19.7	20.0	19.2	18.9	17.9

IN DILUTE ( $>10\%$ ) SOLUTION (43)

Between 0 and 45°C,  $k_1 + k_2$  may be computed with an accuracy of ca. 5% by means of the equation:  $\log_{10} 10^3(k_1 + k_2) = 13.132 - 3472/T$  where  $T$  is the absolute temperature.

EFFECT OF HCL AT 19.7°C (43)

HCl, $N$ .....	0	0.001	0.010	0.0125	0.0166	0.025	0.05	0.10
$10^3(k_1 + k_2)$ ....	17.7	19.0	39.6	46.0	55.8	70.8	125	238

## IN VARIOUS SOLVENTS

Solvent	°C	$10^3(k_1 + k_2)$		$10^3k_1$	$10^3k_2$	Lit.
		$\alpha$	$\beta$			
H <sub>2</sub> O.....	1.5	2.9	2.9			(57)
80% C <sub>2</sub> H <sub>5</sub> OH.....	25	5.4	5.75			(57)
80% C <sub>2</sub> H <sub>5</sub> OH.....	15.0			0.41	1.93	(57)
80% C <sub>2</sub> H <sub>5</sub> OH.....	20.0		3.63	.77	2.86	(44)
H <sub>2</sub> O.....	18.0		17.			(11)
H <sub>2</sub> O.....	19.0		27.3			(61)
Formamide.....	20.0		3.26			(61)

C<sub>6</sub>H<sub>12</sub>O<sub>6</sub>, GALACTOSE

## Optical Rotation

IN VARIOUS SOLVENTS

Solvent	Galactose, g/100 ml	°C	$[\alpha]_D^t$			$10^3(k_1 + k_2)$	Lit.
			$\alpha$	$\alpha \rightleftharpoons \beta$	$\beta$		
H <sub>2</sub> O.....	2.18	12.5	+139.3	+79.3		4.79	(60)
Formamide....	2.01	18.0	154.5	85.45		0.84	(60)
H <sub>2</sub> O.....	2.25	20.0	139.4	79.25		9.60	(61)
Formamide....	1.75	20.0	155.3	87.77		1.98	(61)
H <sub>2</sub> O.....	1.87	20.0		79.01	+56.51	7.22	(61)
Formamide....	1.81	20.0		87.19	62.30	1.57	(61)
H <sub>2</sub> O.....			144.0	80.05	47.0*		(44)
60% C <sub>2</sub> H <sub>5</sub> OH..		20.0	140.6	72.8	33*		(44)
80% C <sub>2</sub> H <sub>5</sub> OH..		20.0	127.2	73.1	34*		(44)
H <sub>2</sub> O.....		20.0			52		(44)
H <sub>2</sub> O.....	1.0	20.0		80.2			(30)

\* Calculated from initial and final solubilities and rotations.

$$\frac{d[\alpha]_D^t}{dt} = -0.23 \text{ at } 12.5^\circ\text{C} = -0.34 \text{ at } 18^\circ\text{C} \text{ (60).}$$

EFFECT OF HCL IN H<sub>2</sub>O (97)

% HCl.....	0	25	37.6	40.0	42.0
°C.....	8	6	6	6	6
$[\alpha]_D^t$ .....	83.3	94.2	113.8	133.6	160.4

EFFECT OF H<sub>2</sub>SO<sub>4</sub> IN H<sub>2</sub>O (11)

$N$ of H <sub>2</sub> SO <sub>4</sub> .....	0	10	16	18	20	24	26
$[\alpha]_D^{25}$ .....	79.0	88.0	95.0	99.5	102.5	110.0	122.0

## EQUILIBRIUM ROTATION

In Aqueous C<sub>2</sub>H<sub>5</sub>OH (13)

% C <sub>2</sub> H <sub>5</sub> OH	$[\alpha]_D^{20}$	$[\alpha]_D^{30}$	$[\alpha]_D^{35}$
30	71.2	66.4	63.3
60	63.3	60.5	57.4
80	57.0	51.0	41.6

In Aqueous *n*-Propyl Alcohol (13, 26)

C <sub>3</sub> H <sub>7</sub> OH, g/l solution	100	200	300	400	500	600
$[\alpha]_D^{20}$ .....	79.66	76.13	74.04	71.56	68.97	64.96

In Various Solvents

Values of  $[\alpha]_\lambda^{20}$  (30)

Galactose, g/100 ml	1	1	2.98
$\lambda$ , m $\mu$	In H <sub>2</sub> O	Pyridine	Formic acid
656	60.50	46.50	101.42
589	80.17	59.83	127.30
535	96.66	76.66	155.30
508	117.50	85.33	175.80
479	131.00	98.66	221.10
447	150.66	115.33	250.80

Index of Refraction and Density of Aqueous Solution (77)

% anhydrous galactose	18.24	9.12	4.60	2.30	1.15
$d_4^{25}$ .....	1.0730	1.0335	1.0150	1.0058	1.0012
$n_D^{25}$ .....	1.3620	1.3470	1.3400	1.3366	1.3349

## Solubility

g  $\alpha$ -galactose per 100 cm<sup>3</sup> solution

Solvent	Initial	Final	Lit.
80% C <sub>2</sub> H <sub>5</sub> OH.....	0.27	0.65	(38)
60% C <sub>2</sub> H <sub>5</sub> OH.....	1.1	3.1	(38)

## Mutarotation (12)

Solvent	Galactose, g/100 ml	°C	$10^3(k_1 + k_2)$
Conductivity H <sub>2</sub> O.....	9.0	25.0	1.41
0.5N H <sub>3</sub> BO <sub>3</sub> .....	9.0	25.0	1.45

C<sub>5</sub>H<sub>10</sub>O<sub>5</sub>, ARABINOSE

## Optical Rotation and Mutarotation

IN VARIOUS SOLVENTS

Solvent	Arabinose, g/100 ml	°C	$[\alpha]_D^t$			$10^3(k_1 + k_2)$	Lit.
			$\alpha$	$\alpha \rightleftharpoons \beta$	$\beta$		
H <sub>2</sub> O.....	2.61	12		+105.9( <i>l</i> -)	+186( <i>l</i> -)	13.4	(60)
H <sub>2</sub> O.....		20	-54*( <i>d</i> -)	-105.0( <i>d</i> -)	-175( <i>d</i> -)	31	(44)
80% C <sub>2</sub> H <sub>5</sub> OH...		20	-28*( <i>d</i> -)	-81.7( <i>d</i> -)	-173( <i>d</i> -)		(44)
Formamide.....	2.40	13		+116.3( <i>l</i> -)	+189( <i>l</i> -)	1.54	(60)

\* Calculated from initial and final solubilities and rotations.

EFFECT OF HCL IN AQUEOUS SOLUTION

Arabinose, ca. 5 g/100 ml (97)

% HCl....	0	25	37.6	40	42
°C.....	9	8	8	8	8
$[\alpha]_D^t$ .....	+105.1	117.6	142.0	166.2	202.9
40% HCl	$t$ , min	6	18	48	64
	$[\alpha]_D^{10}$	+166.3	167.0	167.0	167.0

## Solubility (44)

In 80% aqueous C<sub>2</sub>H<sub>5</sub>OH: Initial  $S_\beta = 0.74$ , final  $S_\beta = 1.94$  g per 100 cm<sup>3</sup> solution. Equilibrium mixture = 38%  $\beta$ , 62%  $\alpha$ .

**C<sub>5</sub>H<sub>10</sub>O<sub>5</sub>, XYLOSE****Optical Rotation and Mutarotation  
IN VARIOUS SOLVENTS**

Solvent	Xylose, g/100 ml	°C	[α] <sub>D</sub> <sup>t</sup>			10 <sup>3</sup> (k <sub>1</sub> + k <sub>2</sub> )	Lit.
			α	α ⇌ β	β		
H <sub>2</sub> O.....		20	+ 92.0	+19.0	-20*		(44)
80% C <sub>2</sub> H <sub>5</sub> OH		20	+ 94.5	+32.1	-20*		(44)
H <sub>2</sub> O.....		1				2.8	(44)
H <sub>2</sub> O.....		10				7.5	(44)
H <sub>2</sub> O.....		20				20.7	(44)
H <sub>2</sub> O.....		30				53.2	(44)
H <sub>2</sub> O.....		40				133	(44)
H <sub>2</sub> O.....	2.72	20	+ 90.3	+19.13		18.8	(60)
Formamide..	4.04	20	+109.4	+25.12		3.06	(60)
H <sub>2</sub> O.....		20		+18.2			(30)
Pyridine....		20		+40.5			(30)
Formic acid.		20		+66.6			(30)

\* Calculated from initial and final solubilities and rotations of the α-form.

**EFFECT OF HCL IN AQUEOUS SOLUTION (ca. 5 g/100 ml) (97)**

% HCl.....	0	8	25	37.6	40.0	42.0
°C.....	13	9	9	9	9	9
[α] <sub>D</sub> <sup>t</sup> .....	+17.6	21.3	27.4	46.4	68.7	96.6

**ROTATION AT EQUILIBRIUM (30)**Values of [α]<sub>λ</sub><sup>20</sup> for α ⇌ β

Xylose, g/100 ml λ, mμ	0.866	1.28	5.48
	In H <sub>2</sub> O	Pyridine	Formic acid
656	+13.28	32.04	55.74
589	18.19	40.64	66.60
535	21.08	48.64	82.66
508	24.50	59.90	95.80
479	27.70	68.34	116.13
447	31.94	72.47	125.95

**Solubility**In 80% C<sub>2</sub>H<sub>5</sub>OH at 20°C: Initial 2.7 g, final 6.2 g per 100 cm<sup>3</sup> solution. Equilibrium mixture, 44% α, 56% β (44).**C<sub>18</sub>H<sub>32</sub>O<sub>16</sub> + 5H<sub>2</sub>O, RAFFINOSE (MELITRIOSE, GOSSYPOSE)**(Composition: *d*-Galactose < *d*-Glucose < *d*-Fructose)

Raffinose may be hydrolyzed to (1) fructose and melibiose; (2) galactose and sucrose; (3) fructose, glucose, and galactose. It is nonreducing.

**Optical Rotation**IN H<sub>2</sub>O

Form		Lit.
R · 5H <sub>2</sub> O.....	[α] <sub>D</sub> <sup>20</sup> = 104.5	(16, 54)
Anhyd.....	[α] <sub>589.25</sub> <sup>25</sup> = 123.00	(62, 91, 93)
Anhyd.....	[α] <sub>546.1</sub> <sup>25</sup> = 144.55	(94)

$$\frac{d[\alpha]_{\lambda}}{dt} = \text{ca. } 0.0 \text{ between } 3^{\circ} \text{ and } 20^{\circ}\text{C (23).}$$

**IN VARIOUS SOLVENTS (30)**C = 3.7125 g anhyd. raffinose per 100 ml solution. Values of [α]<sub>λ</sub><sup>20</sup>

λ, mμ =	656	589	535	508	479	447
In H <sub>2</sub> O.....	79.63	105.20	131.71	150.75	163.77	188.55
Pyridine....	94.22	117.17	142.76	167.00	188.52	218.26

**EFFECT OF SALTS IN H<sub>2</sub>O (91, 92, 93, 94)**0.1 formula weight C<sub>18</sub>H<sub>32</sub>O<sub>16</sub> in 1000 g H<sub>2</sub>O

Salt	Moles/1000 g H <sub>2</sub> O	[α] <sub>589.25</sub> <sup>25</sup>
	0.0	123.00
KCl.....	1.3	123.08
NaCl.....	1.71	123.12

**EFFECT OF SALTS IN H<sub>2</sub>O (91, 92, 93, 94).—(Continued)**

Salt	Moles/1000 g H <sub>2</sub> O	[α] <sub>589.25</sub> <sup>25</sup>
LiCl.....	1.30	123.24
	0.0	[α] <sub>546.1</sub> <sup>24</sup>
		144.55
CsCl.....	1.2	144.64

**Density of Aqueous Solution***d*<sub>20</sub><sup>20</sup> of aqueous solution containing 28.4% raffinose = 1.12474. Since this corresponds to 29.10° sucrose Brix, 1% raffinose = 1.025° sucrose Brix (80).C = formula weights of raffinose · 5H<sub>2</sub>O per liter of solution at *t*°C, all weights *in vacuo* (95).

C	°C	<i>d</i> <sub>t</sub> <sup>t</sup>	C	°C	<i>d</i> <sub>t</sub> <sup>t</sup>
0.038083	0.00	1.00796	0.102297	24.94	1.01179
.037973	24.94	1.00483	.131202	0.00	1.02752
.037615	49.87	.99556	.130727	24.96	1.02378
.058632	0.00	1.01218	.129787	50.12	1.01407
.058466	24.94	1.00897	.176625	0.00	1.03645
.057925	49.87	.99964	.175818	24.00	1.03172
.102676	0.00	1.02147	.174336	49.84	1.02302

**Solubility**IN H<sub>2</sub>O. PER CENT ANHYD. RAFFINOSE

°C.....	0	10	16	24
%.....	6.5	10.0	14.5	28.4
Lit.....	(15)	(15)	(15)	(80)

**IN AQUEOUS CH<sub>3</sub>OH AT 15°C***S* in g anhyd. raffinose per 100 cm<sup>3</sup> solution (31)

Vol. % CH <sub>3</sub> OH.....	100	95	90	85	80	60	20
<i>S</i> .....	10.2	7.5	2.4	1.8	1.8	2.8	5.0

**Hydrolysis of Raffinose by Acids at 25°C (1)**100 g H<sub>2</sub>O + 0.25 mole of anhyd. raffinose + 1 mole of acid

Acid	HNO <sub>3</sub>	HCl	H <sub>2</sub> SO <sub>4</sub>
$k = \frac{1}{t} \log_{10} \frac{a}{a-x}$ .....	0.00390	0.00419	0.00446

**SYSTEMS CONTAINING MORE THAN ONE SUGAR****Solubilities**

SYSTEM: SUCROSE, DEXTROSE, WATER, 30°C (50)

Solid phase	% sucrose	% dextrose	<i>d</i> <sub>4</sub> <sup>30</sup>
C <sub>12</sub> H <sub>22</sub> O <sub>11</sub> .....	68.11	0	1.3301
	64.22	4.89	1.3356
	60.40	9.70	1.3411
	53.19	18.58	1.3507
	48.60	24.61	1.3588
C <sub>12</sub> H <sub>22</sub> O <sub>11</sub> + C <sub>6</sub> H <sub>12</sub> O <sub>6</sub> · H <sub>2</sub> O.....	47.10	26.59	
C <sub>6</sub> H <sub>12</sub> O <sub>6</sub> · H <sub>2</sub> O .....	33.79	33.88	1.3227
	19.66	41.97	1.2867
	7.35	50.00	1.2592
	0	54.64	1.2434

**SOLUBILITY OF SUCROSE, DEXTROSE, AND LEVULOSE IN THE PRESENCE OF ONE ANOTHER**

Solid phase sucrose (50)

23.15°C	% invert sugar.....	0	11.90	25.39	36.90
	% sucrose.....	67.59	57.84	47.31	38.66



## At 30°C

% invert sugar	% sucrose	$d_4^{20}$	% invert sugar	% sucrose	% invert sugar	% sucrose
0	68.11	1.3301	24.52	48.93	47.62*	31.85
14.94	56.32	1.3485	28.01	46.36	56.37	26.03
21.86	50.97	1.3571	37.48	39.23	63.68	21.18
23.21	49.91	1.3587	47.02*	32.06	64.47	20.59
24.46	48.95	1.3608				

\*  $d_4^{20} = 1.3957$ .

## At 50°C

% invert sugar	0	11.42	22.65	32.32	46.05	57.06
% sucrose	72.25	62.81	53.80	46.20	35.75	28.18

## Both sugars present as solid phases (50)

°C	0	10	15	23.15	30	40	50
% sucrose	43.7	40.9	39.1	36.3	33.6	31.1	27.7
% invert sugar	27.2	31.8	34.8	39.9	45.4	50.7	58.0

## SYSTEM: DEXTROSE, LEVULOSE, WATER, 30°C

## Solid phase dextrose monohydrate (50)

% anhyd. dextrose	% levulose	$d_4^{20}$	% anhyd. dextrose	% levulose	$d_4^{20}$
54.64	0.00		35.76	33.09	1.3286
49.34	8.94	1.2639	34.48	35.69	1.3359
49.32	8.94	1.2650	33.67	37.10	1.3408
45.97	14.50	1.2779	32.55	39.39	1.3480
41.01	23.23	1.3000			

## SYSTEM: DEXTROSE, LEVULOSE, WATER

Solid phase, dextrose. A = % dextrose, in water alone. B = % dextrose in solution containing an equivalent amount of levulose. Saturation with crystalline dextrose in both cases (50).

°C	A	B	°C	A	B
0	35.0	50.8	30.0	54.64	69.7
10.0	40.8	56.6	35.0	58.02	72.2
15.0	44.0	59.8	40.0	61.87	74.8
20.0	47.2	62.6	45.0	65.71	78.0
25.0	50.80	66.2	50.0	70.91	81.9

## Clerget Analysis for Sucrose (48)

The estimation of sucrose in the presence of other optically active substances by the Clerget Method depends upon the change of rotation which the sugar undergoes upon inversion. The difference in saccharimeter deg. between the rotation of 26 g of pure

sucrose in 100 ml of solution observed in a 200 mm column and the rotation of invert sugar calculated to a concentration of 26 g of inverted sucrose in 100 ml is known as the Clerget Divisor. Two general methods of inversion are employed:

- Inversion by the enzyme, invertase.<sup>1</sup>
- Inversion by hydrochloric acid.<sup>2</sup>

## VALUES OF CLERGET DIVISOR

( $m_s$ , resp.  $m_A$ , resp.  $m_N$ , resp.  $m_{Na} =$  g inverted sucrose, resp. HCl, resp.  $\text{NH}_4\text{Cl}$ , resp.  $\text{NaCl}$  in 100 ml of solution.  $t = ^\circ\text{C}$ .)

- Invertase inversion.

Positive constituent	Negative constituent
+100	$-42.1 - 0.0676(m_s - 13) + t/2$

- HCl inversion, 2.312 g anhyd. HCl in 100 ml of inverted solution, equivalent to 10 ml of HCl ( $d_4^{20} = 1.1029$ ).

Positive constituent	Negative constituent
+100	$-43.25 - 0.0676(m_s - 13) + t/2$

- HCl inversion and subsequent neutralization with  $\text{NH}_4\text{OH}$  equivalent to 10 ml HCl ( $d_4^{20} = 1.1029$ ) in 100 ml of inverted solution.

Positive constituent	Negative constituent
+100	$-43.91 - 0.0676(m_s - 13) + t/2$

- HCl inversion with 10 ml of HCl ( $d_4^{20} = 1.1029$ ) in 100 ml of inverted solution; 2.315 g NaCl contained in 100 ml of solution for direct polarization (in order to equalize the effect of HCl upon invert sugar when present as an impurity).

Positive constituent	Negative constituent
+99.38	$-42.1 - 0.0676(m_s - 13) + t/2$

- HCl inversion with 10 ml HCl ( $d_4^{20} = 1.1029$ ) in 100 ml of inverted solution and subsequent neutralization with  $\text{NH}_4\text{OH}$ ; 3.392 g  $\text{NH}_4\text{Cl}$  contained in 100 ml of solution for direct polarization.

Positive constituent	Negative constituent
+99.43	$-43.91 - 0.0676(m_s - 13) + t/2$

## GENERALIZED FORMULAE

Positive constituent:  $R = 100 - 0.265 m_{Na} = 100 - 0.169 m_N$ .

Negative constituent:  $R_{\text{HCl}} = -41.12 - 0.5407 m_A - 0.0676 m_s + 0.5 t$ .  $R_{\text{NH}_4\text{Cl}} = -41.12 - 0.563 m_N - 0.0676 m_s + 0.5 t$ .

## Reducing Powers toward Fehling's Solution

For Munson and Walker's table for calculating dextrose, invert sugar, in mixtures containing sucrose, lactose and maltose *v.* (18, 65). For Allihn's tables *v.* (14, 20).

<sup>1</sup> For detailed description of methods of inversion by invertase, *v.* (3).

<sup>2</sup> For detailed description of methods of inversion by hydrochloric acid, *v.* (48).

## ROTATIONS AND MELTING POINTS OF PURE SUGARS AND SUGAR DERIVATIVES (40-5)

	Formula	Mol. wt.	M. P.	$[\alpha]_D^{20}$	$[M]_D^{20}$	Solvent
$\beta$ -D-Arabinose	$\text{C}_5\text{H}_{10}\text{O}_5$	150		-175	-26 300	$\text{H}_2\text{O}$
$\alpha$ -L-Arabinose tetraacetate	$\text{C}_{13}\text{H}_{18}\text{O}_9$	318	97	+42.5	+13 500	$\text{CHCl}_3$
$\beta$ -L-Arabinose tetraacetate	$\text{C}_{13}\text{H}_{18}\text{O}_9$	318	86	+147.2	+46 800	$\text{CHCl}_3$
L-Arabonic amide	$\text{C}_5\text{H}_{11}\text{O}_5\text{N}$	165	136	+37.5	+6 190	$\text{H}_2\text{O}$
D-Arabonic phenylhydrazide	$\text{C}_{11}\text{H}_{16}\text{O}_5\text{N}_2$	256		-14.5	-3 710	$\text{H}_2\text{O}$
$\beta$ -Bromoacetyl D-arabinose	$\text{C}_{11}\text{H}_{15}\text{O}_7\text{Br}$	339		-288	-97 600	$\text{CHCl}_3$
$\beta$ -Bromoacetyl L-arabinose	$\text{C}_{11}\text{H}_{15}\text{O}_7\text{Br}$	339		+288	+97 600	$\text{CHCl}_3$
$\alpha$ -Bromoacetyl lactose	$\text{C}_{26}\text{H}_{35}\text{O}_{17}\text{Br}$	699	145	+109	+76 200	$\text{CHCl}_3$
$\alpha$ -Bromoacetyl D-xylose	$\text{C}_{11}\text{H}_{15}\text{O}_7\text{Br}$	339	102	+212	+71 900	$\text{CHCl}_3$
$\beta$ -Cellobiose	$\text{C}_{12}\text{H}_{22}\text{O}_{11}$	342		+16.0	+5 470	$\text{H}_2\text{O}$
$\alpha$ -Cellobiose octaacetate	$\text{C}_{28}\text{H}_{38}\text{O}_{19}$	678	229	+41	+27 800	$\text{CHCl}_3$
$\beta$ -Cellobiose octaacetate	$\text{C}_{28}\text{H}_{38}\text{O}_{19}$	678	202	-14.6	-9 900	$\text{CHCl}_3$
$\alpha$ -Chondrosamine pentaacetate	$\text{C}_{16}\text{H}_{23}\text{O}_{10}\text{N}$	389	183	+101.3	+39 400	$\text{CHCl}_3$
$\beta$ -Chondrosamine pentaacetate	$\text{C}_{16}\text{H}_{23}\text{O}_{10}\text{N}$	389	220 d	+10.5	+4 080	$\text{CHCl}_3$
$\beta$ -Chloroacetyl D-arabinose	$\text{C}_{11}\text{H}_{15}\text{O}_7\text{Cl}$	295		-244	-72 000	$\text{CHCl}_3$

## ROTATIONS AND MELTING POINTS OF PURE SUGARS AND SUGAR DERIVATIVES (40.5).—(Continued)

	Formula	Mol. wt.	M. P.	$[\alpha]_D^{20}$	$[M]_D^{20}$	Solvent
$\beta$ -Chloroacetyl <i>l</i> -arabinose.....	$C_{11}H_{15}O_7Cl$	295		+244	+ 72 000	$CHCl_3$
Chloroacetyl cellobiose(40).....	$C_{26}H_{35}O_{17}Cl$	655	138	+ 59.2	+ 38 800	$CHCl_3$
Chloroacetyl <i>d</i> -galactose (second).....	$C_{14}H_{19}O_9Cl$	367	67	— 78	— 28 600	$CHCl_3$
$\alpha$ -Chloroacetyl lactose.....	$C_{26}H_{35}O_{17}Cl$	655	121	+ 84	+ 55 000	$CHCl_3$
$\alpha$ -Chloroacetyl neolactose (53).....	$C_{26}H_{35}O_{17}Cl$	655	182	+ 71.2	+ 46 700	$CHCl_3$
$\beta$ - <i>d</i> -Fructose.....	$C_6H_{12}O_6$	180		—133.5	— 24 000	$H_2O$
$\alpha$ - <i>d</i> -Fructose pentaacetate.....	$C_{16}H_{22}O_{11}$	390	70	+ 34.7	+ 13 500	$CHCl_3$
$\beta$ - <i>d</i> -Fructose pentaacetate.....	$C_{16}H_{22}O_{11}$	390		—120.9	— 47 200	$CHCl_3$
$\beta$ - <i>d</i> -Fructose tetraacetate.....	$C_{14}H_{20}O_{10}$	348		— 91.6	— 31 900	$CHCl_3$
<i>d</i> -Galactonic amide.....	$C_6H_{13}O_6N$	195	172	+ 30.2	+ 5 890	$H_2O$
$\alpha$ - <i>d</i> -Galactose.....	$C_6H_{12}O_6$	180		+144	+ 25 900	$H_2O$
$\beta$ - <i>d</i> -Galactose.....	$C_6H_{12}O_6$	180		+ 52	+ 9 360	$H_2O$
<i>d</i> -Galactose pentaacetate (first).....	$C_{16}H_{22}O_{11}$	390	142	+ 23	+ 8 970	$CHCl_3$
<i>d</i> -Galactose pentaacetate (second).....	$C_{16}H_{22}O_{11}$	390	96	+107	+ 41 700	$CHCl_3$
<i>d</i> -Galactose pentaacetate (third).....	$C_{16}H_{22}O_{11}$	390	98	— 42	— 16 400	$CHCl_3$
<i>d</i> -Galactose pentaacetate (fourth).....	$C_{16}H_{22}O_{11}$	390	87	+ 61	+ 23 800	$CHCl_3$
<i>d</i> -Galactose tetraacetate (third).....	$C_{14}H_{20}O_{10}$	348	73	— 17.8	— 6 190	$CHCl_3$
<i>d</i> -Galactose phenylhydrazone.....	$C_{20}H_{26}O_9N_2$	438	95	+ 15.5	+ 6 790	$CHCl_3$
<i>d</i> - $\alpha$ -Galaheptonic amide.....	$C_7H_{15}O_7N$	225	206	+ 14.3	+ 3 220	$H_2O$
<i>d</i> - $\alpha$ -Galaheptonic phenylhydrazide.....	$C_{13}H_{20}O_7N_2$	316		+ 8.5*	+ 2 700*	$H_2O$
$\alpha$ -Gentiobiose octaacetate.....	$C_{28}H_{38}O_{19}$	678	189	+ 52.4	+ 35 500	$CHCl_3$
$\beta$ -Gentiobiose octaacetate.....	$C_{28}H_{38}O_{19}$	678	193	— 5.3	— 3 590	$CHCl_3$
<i>d</i> - $\alpha$ -Glucoheptonic amide.....	$C_7H_{15}O_7N$	225	134	+ 10.6	+ 2 390	$H_2O$
<i>d</i> - $\beta$ -Glucoheptonic amide.....	$C_7H_{15}O_7N$	225	158	— 30.2	— 6 790	$H_2O$
<i>d</i> - $\alpha$ -Glucoheptonic phenylhydrazide.....	$C_{13}H_{20}O_7N_2$	316		+ 9.3	+ 2 940	$H_2O$
$\beta$ - <i>d</i> - $\alpha$ -Glucoheptose.....	$C_7H_{14}O_7$	210		— 28.4	— 5 960	$H_2O$
$\alpha$ - <i>d</i> - $\alpha$ -Glucoheptose hexaacetate.....	$C_{19}H_{26}O_{13}$	462	164	+ 87.0	+ 40 200	$CHCl_3$
$\beta$ - <i>d</i> - $\alpha$ -Glucoheptose hexaacetate.....	$C_{19}H_{26}O_{13}$	462	135	+ 4.8	+ 2 220	$CHCl_3$
<i>d</i> -Gluconic amide.....	$C_6H_{13}O_6N$	195	144	+ 31.2	+ 6 080	$H_2O$
$\alpha$ - <i>d</i> -Glucosamine pentaacetate.....	$C_{16}H_{23}O_{10}N$	389	140	+ 93.5	+ 36 400	$CHCl_3$
$\beta$ - <i>d</i> -Glucosamine pentaacetate.....	$C_{16}H_{23}O_{10}N$	389	189	+ 1.2	+ 467	$CHCl_3$
$\alpha$ - <i>d</i> -Glucose.....	$C_6H_{12}O_6$	180		+113	+ 20 300	$H_2O$
$\beta$ - <i>d</i> -Glucose.....	$C_6H_{12}O_6$	180		+ 19	+ 3 420	$H_2O$
$\alpha$ - <i>d</i> -Glucose pentaacetate.....	$C_{16}H_{22}O_{11}$	390	113	+101.6	+ 39 600	$CHCl_3$
$\beta$ - <i>d</i> -Glucose pentaacetate.....	$C_{16}H_{22}O_{11}$	390	132	+ 3.8	+ 1 480	$CHCl_3$
<i>d</i> -Gulonic amide.....	$C_6H_{13}O_6N$	195	123	+ 15.2	+ 2 960	$H_2O$
$\alpha$ -Iodoacetyl lactose.....	$C_{26}H_{35}O_{17}I$	746	145	+137	+102 000	$CHCl_3$
$\alpha$ -Lactose.....	$C_{12}H_{22}O_{11}$	342		+ 90	+ 30 800	$H_2O$
$\beta$ -Lactose.....	$C_{12}H_{22}O_{11}$	342		+ 35	+ 12 000	$H_2O$
$\alpha$ -Lactose octaacetate.....	$C_{28}H_{38}O_{19}$	678	152	+ 53.9	+ 36 500	$CHCl_3$
$\beta$ -Lactose octaacetate.....	$C_{28}H_{38}O_{19}$	678	90	— 4.3	— 2 920	$CHCl_3$
$\alpha$ - <i>d</i> -Lyxose.....	$C_6H_{10}O_5$	150		+ 5.5	+ 825	$H_2O$
$\beta$ -Maltose.....	$C_6H_{12}O_6$	342		+118	+ 40 400	$H_2O$
$\beta$ -Maltose heptaacetate.....	$C_{26}H_{36}O_{18}$	636	181	+ 67.8	+ 43 100	$CHCl_3$
$\alpha$ -Maltose octaacetate.....	$C_{28}H_{38}O_{19}$	678	125	+122.4	+ 83 000	$CHCl_3$
$\beta$ -Maltose octaacetate.....	$C_{28}H_{38}O_{19}$	678	160	+ 62.7	+ 42 500	$CHCl_3$
<i>d</i> -Mannitol hexaacetate.....	$C_{18}H_{26}O_{12}$	434	120	+ 26	+ 11 300	$CHCl_3$
<i>d</i> - $\alpha$ -Mannoheptonic amide.....	$C_7H_{15}O_7N$	225	194	+ 28	+ 6 300	$H_2O$
<i>d</i> - $\alpha$ -Mannoheptonic phenylhydrazide.....	$C_{13}H_{20}O_7N_2$	316		+ 21	+ 6 640	$H_2O$
<i>d</i> - $\alpha$ -Mannoheptose hexaacetate (first).....	$C_{19}H_{26}O_{13}$	462	106	+ 24.2	+ 11 200	$CHCl_3$
<i>d</i> - $\alpha$ -Mannoheptose hexaacetate (second).....	$C_{19}H_{26}O_{13}$	462	140	— 31	— 14 300	$CHCl_3$
<i>d</i> -Mannonic amide.....	$C_6H_{13}O_6N$	195	173	— 17.3	— 3 370	$H_2O$
<i>d</i> -Mannonic phenylhydrazide.....	$C_{12}H_{18}O_6N_2$	286		— 8.1*	— 2 320*	$H_2O$
<i>d</i> -Mannosaccharic diamide.....	$C_6H_{12}O_6N_2$	208	189	— 24.5	— 5 100	$H_2O$
$\beta$ - <i>d</i> -Mannose.....	$C_6H_{12}O_6$	180		— 17	— 3 060	$H_2O$
$\alpha$ - <i>d</i> -Mannose pentaacetate.....	$C_{16}H_{22}O_{11}$	390	64	+ 55.0	— 21 500	$CHCl_3$
$\beta$ - <i>d</i> -Mannose pentaacetate.....	$C_{16}H_{22}O_{11}$	390	118	— 25.2	— 9 830	$CHCl_3$
Melezitose.....	$C_{18}H_{32}O_{16}$	504	148	+ 88.2	+ 44 500	$H_2O$
Melezitose hendekaacetate.....	$C_{40}H_{64}O_{27}$	966	117	+103.8	+100 000	$CHCl_3$
$\beta$ -Melibiose.....	$C_{12}H_{22}O_{11}$	342		+ 12.4	+ 42 400	$H_2O$
$\beta$ -Melibiose octaacetate.....	$C_{28}H_{38}O_{19}$	678	177	+102.5	+ 69 500	$CHCl_3$



## ROTATION AND MELTING POINTS OF PURE SUGARS AND SUGAR DERIVATIVES (40.5)—(Continued)

	Formula	Mol. wt.	M. P.	$[\alpha]_D^{20}$	$[M]_D^{20}$	Solvent
$\alpha$ -Methyl <i>l</i> -arabinoside.....	$C_6H_{12}O_5$	164	131	+ 17.3	+ 2 840	H <sub>2</sub> O
$\beta$ -Methyl <i>l</i> -arabinoside.....	$C_6H_{12}O_5$	164	169	+245.5	+ 40 300	H <sub>2</sub> O
$\beta$ -Methyl <i>l</i> -arabinoside triacetate.....	$C_{12}H_{18}O_8$	290	85	+182.0†	+ 52 800†	CHCl <sub>3</sub>
$\beta$ -Methyl cellobioside heptaacetate.....	$C_{27}H_{38}O_{18}$	650	187	- 25.4	- 16 500	CHCl <sub>3</sub>
$\beta$ -Methyl <i>d</i> -fructoside.....	$C_7H_{14}O_6$	194	120	-172.1	- 33 400	H <sub>2</sub> O
$\beta$ -Methyl <i>d</i> -fructoside tetraacetate.....	$C_{15}H_{22}O_{10}$	362	76	-124.6	- 45 100	CHCl <sub>3</sub>
$\alpha$ -Methyl <i>d</i> -galactoside tetraacetate.....	$C_{15}H_{22}O_{10}$	362		+133.0	+ 48 100	CHCl <sub>3</sub>
$\beta$ -Methyl <i>d</i> -galactoside tetraacetate.....	$C_{15}H_{22}O_{10}$	362		- 13.0	- 4 710	CHCl <sub>3</sub>
$\beta$ -Methyl gentiobioside.....	$C_{13}H_{24}O_{11}$	356	98	- 36.0	- 12 800	H <sub>2</sub> O
$\beta$ -Methyl gentiobioside heptaacetate.....	$C_{27}H_{38}O_{18}$	650	82	- 18.9	- 12 300	CHCl <sub>3</sub>
$\alpha$ -Methyl <i>d</i> -glucoside tetraacetate.....	$C_{15}H_{22}O_{10}$	362	101	+130.6	+ 47 300	CHCl <sub>3</sub>
$\beta$ -Methyl <i>d</i> -glucoside tetraacetate.....	$C_{15}H_{22}O_{10}$	362	105	- 18.3	- 6 620	CHCl <sub>3</sub>
$\alpha$ -Methyl <i>d</i> -lyxoside (73).....	$C_6H_{12}O_5$	164	109	+ 59.4		H <sub>2</sub> O
$\beta$ -Methyl maltoside heptaacetate.....	$C_{27}H_{38}O_{18}$	650	125	+ 53.7	+ 34 900	CHCl <sub>3</sub>
$\alpha$ -Methyl <i>d</i> -xyloside.....	$C_6H_{12}O_5$	164		+153.9	+ 25 200	H <sub>2</sub> O
$\beta$ -Methyl <i>d</i> -xyloside.....	$C_6H_{12}O_5$	164	157	- 65.5	- 10 700	H <sub>2</sub> O
$\alpha$ -Methyl <i>d</i> -xyloside triacetate.....	$C_{12}H_{18}O_8$	290	86	+119.6	+ 34 700	CHCl <sub>3</sub>
$\beta$ -Methyl <i>d</i> -xyloside triacetate.....	$C_{12}H_{18}O_8$	290	115	- 60.7	- 17 600	CHCl <sub>3</sub>
$\alpha$ -Neolaetose octaacetate (53).....	$C_{28}H_{38}O_{19}$	678	178	+ 53.4	+ 36 200	CHCl <sub>3</sub>
$\beta$ -Neolaetose octaacetate (53).....	$C_{28}H_{38}O_{19}$	678	148	- 7.1	- 4 810	CHCl <sub>3</sub>
<i>l</i> -Rhamnomethyltetronic amide.....	$C_5H_{11}O_4N$	149	135	+ 54.8	+ 8 170	H <sub>2</sub> O
<i>l</i> -Rhamnomethyltetronic lactone.....	$C_5H_8O_4$	132	123	- 44.7	- 5 900	H <sub>2</sub> O
<i>l</i> -Rhamnonie phenylhydrazide.....	$C_{12}H_{18}O_5N_2$	270		+ 17.2	+ 4 640	H <sub>2</sub> O
$\alpha$ - <i>l</i> -Rhamnose.....	$C_5H_{12}O_5$	164		- 7.7	- 1 260	H <sub>2</sub> O
<i>l</i> -Ribonie amide.....	$C_5H_{11}O_5N$	165	138	- 16.4	- 2 710	H <sub>2</sub> O
<i>d</i> -Saccharic diamide.....	$C_6H_{12}O_6N_2$	208	173	+ 13.3	+ 2 770	H <sub>2</sub> O
Sedoheptose (anhydro-).....	$C_7H_{12}O_6$	210		-146.3	- 30 720	H <sub>2</sub> O
Sucrose octaacetate.....	$C_{28}H_{38}O_{19}$	678	69	+ 59.6	+ 40 400	CHCl <sub>3</sub>
Trehalose octaacetate.....	$C_{28}H_{38}O_{19}$	678	98	+162.3	+110 000	CHCl <sub>3</sub>
$\alpha$ - <i>d</i> -Xylose.....	$C_5H_{10}O_5$	150		+ 92	+ 13 800	H <sub>2</sub> O
$\alpha$ - <i>d</i> -Xylose tetraacetate.....	$C_{13}H_{18}O_9$	318	59	+ 89.1	+ 28 300	CHCl <sub>3</sub>
$\beta$ - <i>d</i> -Xylose tetraacetate.....	$C_{13}H_{18}O_9$	318	128	- 24.9	- 7 920	CHCl <sub>3</sub>
<i>d</i> -Xylose triacetate.....	$C_{11}H_{16}O_8$	276	141	+ 70†	+ 19 300†	CHCl <sub>3</sub>

\* At 80°C. † At 23°C.

## LITERATURE

(For a key to the periodicals see end of volume)

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# X-RAY DIFFRACTION DATA— MISCELLANEOUS NATURAL AND INDUSTRIAL MATERIALS

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The following bibliography contains references to qualitative and quantitative studies by means of X-rays on various natural and industrial materials, and supplements the quantitative data on pure metals, alloys, soaps, etc., presented in vol. I, p. 338-353. The following classes of materials are covered: I. Structure of Alloys. II. Non-ferrous Metals and Alloys. III. Iron and Steel. IV. Worked Metals and Alloys. V. Orientation of Crystals in Electrodeposited Metals. VI. Fibrous or Deformed Substances. VII. Cellulose and Related Compounds. VIII. Rubber and Related Compounds. IX. Ceramic Materials and Products. X. Glass and Silica. XI. Catalysts. XII. Amorphous and Colloidal Materials. XIII. Application to the Identification of Compounds.

## I. STRUCTURE OF ALLOYS

- (<sup>1</sup>) Hadfield, Main and Brooksbank, *83*, **15** II: 72; 20 (steels). (<sup>2</sup>) Bain, *33*, **25**: 657; 21 (crystal structure). (<sup>3</sup>) Bain, *80*, **68**: 625; 23 (crystal structure of solid solutions). (<sup>4</sup>) Wever, *Bericht No. 24 des Werkstoffausschusses der Ver. deutscher Eisenhüttenleute*, Oct. 5, 1922 (structure of metals). (<sup>5</sup>) Jeffries and Archer, *33*, **29**: 923, 966; 23 (solid solutions). (<sup>6</sup>) Rosenhain, *58*, **112**: 832; 23 (solid solutions and inter-metallic compounds). (<sup>7</sup>) Rosenhain, *115*, **115**: 591; 23 (inner structure of alloys). (<sup>8</sup>) St. John, *430*, **112**: 890, 908; 23 (X-rays in the steel industry). (<sup>9</sup>) Bain, *45*, **16**: 692; 24 (X-ray crystal analysis in metallurgy). (<sup>10</sup>) Becker, *Metallbörse*, **14**: 297, 346, 395, 442; 24 (X-rays in chemical research). (<sup>11</sup>) Andrew, *J. Roy. Tech. Coll. Glasgow*, No. 2: 63; 25 (crystal-line structure of metals). (<sup>12</sup>) Czochralski, *218*, **13**: 425, 455; 25. *95*, **17**: 1; 25 (metallography and physical research). (<sup>13</sup>) Glöcker, *95*, **16**: 180; 24 (testing of materials). (<sup>14</sup>) Jeffries, *66*, **25** I: 444; 25 (X-ray metallography). (<sup>15</sup>) Rosenhain, *325*, **24**: 361; 25 (inner structure of alloys). (<sup>16</sup>) Weiss, *198*, **36**: 397; 25. *74*, **22**: 333, 450; 25 (X-ray spectrography and the study of metals). (<sup>17</sup>) Weiss, *5*, **108**: 643; 25 (X-rays and the study of alloys). (<sup>18</sup>) Westgren and Phragmén, *55*, Special No., April 1, 1925, p. 86 (structure of alloys). (<sup>19</sup>) Westgren, *Sartryck ur Teknisk Tidsk.*, 1925, häft 22 (solid solutions). (<sup>20</sup>) Aborn and Burgmann, *The Tech. Engineering News*, April, 1926, p. 2 (ultimate structure of metals). (<sup>21</sup>) Rinne, *95*, **18**: 37, 81; 26 (models for the mechanics of metals). (<sup>22</sup>) Tammann, *8*, **79**: 81; 26 (distribution of two kinds of atoms in mixed crystals). (<sup>23</sup>) Westgren and Phragmén, *95*, **18**: 279; 26 (metallic systems). (<sup>24</sup>) Westgren and Phragmén, *20*, **19B**: No. 12; 26 (structure analogies of alloys).

## II. STRUCTURES OF NON-FERROUS METALS AND ALLOYS

- (<sup>1</sup>) Imai, *159*, **11**: 313; 22 (Cu-Zn). (<sup>2</sup>) McKeehan, *Ann. Postes, Télégr. Téléph.*, **12**: 1303; 23. *47*, **32**: 564; 24 (K, Be, BeO, and Ag-Pd and Au-Ag alloys). (<sup>3</sup>) Davey, *2*, **26**: 736; 25 (W). (<sup>4</sup>) Johansson and Linde, *8*, **78**: 439; 25 (Au-Cu and Pd-Cu). (<sup>5</sup>) Krüger and Sacklowski, *8*, **78**: 72; 25 (Pd-Ag alloys containing H). (<sup>6</sup>) Anderson, *143*, **201**: 465; 26 (duralumin and its crystal structure). (<sup>7</sup>) Bradley and Ollard, *58*, **117**: 122; 26 (Cr). (<sup>8</sup>) Freeman and Brandt, *31A*, **20**: 661, 695; 26 (Zn). (<sup>9</sup>) Friauf, *1*, **48**: 1906; 26 (magnesium plumbide). (<sup>10</sup>) Harang, *63*, **27**: 204; 26 (Heusler alloys). (<sup>11</sup>) Holgersson, *8*, **79**: 35; 26 (Au-Ag and Ni-Cu). (<sup>12</sup>) Sillers, *31A*, **20**: 686; 26. Cf. Pierce, Anderson and Van Dyck, *143*, **200**: 363; 25 (Zn). (<sup>13</sup>) Westgren and Phragmén, *468*, **2**: 1926 (Cr-C). (<sup>14</sup>) Westgren and Phragmén, *93*, **156**: 27; 26 (W-C and Mo-C).

## III. CRYSTAL STRUCTURE OF IRON AND STEEL

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- (<sup>1</sup>) Iokibe, *159*, **9**: 275; 20 (graphite and temper-carbon from cast iron). (<sup>2</sup>) Westgren, *220*, **105**: 401; 21 (steel). (<sup>3</sup>) Westgren, *140*, **103**: 303; 21. *115*, **111**: 727, 757; 21 (iron and steel). (<sup>4</sup>) Westgren and Lindh, *7*, **98**: 181; 21 (iron and steel). (<sup>5</sup>) Wever, *226*, **3**: 45; 21 (arrangement of iron atoms in austenitic steel). (<sup>6</sup>) Bain, *33*, **26**: 543; 22 (martensite formed spontaneously from austenite). (<sup>7</sup>) Tammann, *77*, **42**: 772; 22 (transformation of cementite at 210°). (<sup>8</sup>) Westgren and Phragmén, *140*, **105**: 241; 22 (steel). (<sup>9</sup>) Westgren and Phragmén, *7*, **102**: 1; 22 (iron and steel). (<sup>10</sup>) Wever, *226*, **4**: 67; 22 (iron carbide). (<sup>11</sup>) Wever, *226*, **4**: 81; 22 (graphite and temper-carbon). (<sup>12</sup>) Bain and Jeffries, *430*, **112**: 805; 23 (red hardness in high-speed steel). (<sup>13</sup>) Heaps, *2*, **22**: 486; 23 (crystal structure and

- magnetostriction). (<sup>14</sup>) Okochi, *469*, **2**: 13; 23 (brittleness in electrolytic iron). (<sup>15</sup>) Westgren and Phragmén, *220*, **1923**: 449 (steel). (<sup>16</sup>) Zorning, *471*, **4**: 77; 23 (examination of steel by X-ray spectrometer). (<sup>17</sup>) Bain, *80*, advance copy, Feb., 1924 (martensite). (<sup>18</sup>) Greene, *430*, **114**: 615, 670; 24 (troostite and sorbite). (<sup>19</sup>) Heindlhofer, *2*, **24**: 426; 24 (martensite). (<sup>20</sup>) Heindlhofer and Wright, *212*, **7**: 34; 24 (hardened ball steel). (<sup>21</sup>) Honda, *212*, **6**: 187; 24 (transformation in pure Fe). (<sup>22</sup>) Lucas, *212*, **6**: 669; 24 (austenite and martensite). (<sup>23</sup>) Westgren and Phragmén, *58*, **114**: 94; 24. *140*, **109**: 159; 24 (steel). (<sup>24</sup>) Wever, *9*, **30**: 376; 24 (technical iron). (<sup>25</sup>) Wever and Rütten, *226*, **6**: 1; 24 (solid solution  $\gamma$ -Fe-C). (<sup>26</sup>) Williams, *417*, **13**: 175; 24 (hardened steel). (<sup>27</sup>) Benedicks, *58*, **115**: 230; 25 (hardness of Mn-steel). (<sup>28</sup>) Foley, *80*, **73**: 850; 26 (amorphous cement and the formation of ferrite). (<sup>29</sup>) Honda, *159*, **14**: 165; 25 (formation of martensite in C-steels). (<sup>30</sup>) Wever, *77*, **45**: 1208; 25 (Fe). (<sup>31</sup>) Davey, *120*, **29**: 440; 26 (iron and steel). (<sup>32</sup>) Fink and Campbell, *212*, **9**: 717; 26 (influence of heat treatment and carbon content on pure Fe-C alloys). (<sup>33</sup>) Osawa, *140*, **113**: 447; 26 (lattice-constant and density of Fe-Ni alloys). (<sup>34</sup>) Phragmén, *140*, **1926**, advance paper (Fe-Si alloys).

## IV. X-RAY DIFFRACTION OF WORKED METALS AND ALLOYS

- (<sup>1</sup>) Owen and Black, *58*, **92**: 686; 14 (metallic crystals). (<sup>2</sup>) Schmidt, *63*, **17**: 554; 16 (metals). (<sup>3</sup>) Gross and Blassmann, *190B*, **42**: 728; 19 (wire-forming W crystals). (<sup>4</sup>) Nishikawa and Asahara, *2*, **15**: 38; 20 (metals). (<sup>5</sup>) Bain and Jeffries, *33*, **25**: 775; 21 (mixed orientation in crystals of ductile metals). (<sup>6</sup>) Ettisch, Polanyi and Weissenberg, *63*, **22**: 646; 21 (metals). (<sup>7</sup>) Ettisch, Polanyi and Weissenberg, *96*, **7**: 181; 21 (fibre-structure of Cu and W-wires). (<sup>8</sup>) Ettisch, Polanyi and Weissenberg, *7*, **99**: 332; 21 (fibrous structure of hard-drawn metals). (<sup>9</sup>) Kirchner, *8*, **69**: 59; 22 (experiments on structure). (<sup>10</sup>) Mark, Polanyi and Schmid, *96*, **12**: 58, 78, 111; 22 (drawing Zn crystals). (<sup>11</sup>) Niwa and Matūra, *338*, **122**: 1; 22 (cold rolling of sheet steel). (<sup>12</sup>) Ono, *470*, **2**: 261; 22 (inner structure of strained metals). (<sup>13</sup>) Ono, *470*, **2**: 241; 22 (inner structure of strained Cu-wire). (<sup>14</sup>) Polanyi, *218*, **10**: 411; 22 (crystal arrangement). (<sup>15</sup>) Polanyi, *9*, **28**: 16; 22 (fixing single crystals). (<sup>16</sup>) van Arkel, *208*, **3**: 76; 23 (uni-crystalline W). (<sup>17</sup>) Bain, *33*, **28**: 65; 23 (cored crystals and metallic compounds). (<sup>18</sup>) Czochralski, *95*, **15**: 60, 126; 23 (structure hypotheses). (<sup>19</sup>) Kakinuma, *219*, **5**: 90; 23 (atomistic mechanism of metal rolling). (<sup>20</sup>) Mark and Polanyi, *96*, **18**: 75; 23 (space-lattice, gliding directions and gliding planes in white Sn). (<sup>21</sup>) Mark, Polanyi and Schmid, *218*, **11**: 256; 23 (uni-crystalline Sn-wires). (<sup>22</sup>) Mark and Weissenberg, *96*, **16**: 314; 23 (rolled metal foils). (<sup>23</sup>) Mark and Weissenberg, *96*, **14**: 328; 23 (rolled metal foils). (<sup>24</sup>) Müller, *5*, **105**: 500; 24 (crystal axes in "single-crystal" Al-bars). (<sup>25</sup>) Polanyi, *96*, **17**: 42; 23 (structure changes through cold working). (<sup>26</sup>) Polanyi and Weissenberg, *97*, **4**: 199; 23 (worked metals). (<sup>27</sup>) Thomassen, *95*, **15**: 306; 23 (surface layer of worked metals). (<sup>28</sup>) Bragg, *58*, **113**: 639; 24 (metal film). (<sup>29</sup>) Research Staff of General Electric Co., *3*, **48**: 800; 24 (deformation of W single crystals). (<sup>30</sup>) Glöcker and Kaupp, *95*, **16**: 377; 24 (recrystallization of Ag). (<sup>31</sup>) Gross, *95*, **16**: 18; 24. *47*, **31**: 385; 24 (deformed crystals and the process of work-hardening). (<sup>32</sup>) Kakinuma, *219*, **5**: 150; 24 (atomistic mechanism of metal rolling). (<sup>33</sup>) Lester, *471*, **5**: 455; 24 (crystal deformation in cold-worked steel). (<sup>34</sup>) Polanyi, *97*, **5**: 580; 24 (worked metals). (<sup>35</sup>) Schiebold, *95*, **16**: 417, 462; 24 (hardening phenomena in metals). (<sup>36</sup>) Wever, *96*, **28**: 69; 24 (cubically crystallizing metals after rolling). (<sup>37</sup>) Anderson and Norton, *80*, **71**: 720; 25 (evidence versus the amorphous-metal hypothesis). (<sup>38</sup>) van Arkel, *208*, **5**: 208; 25. *218*, **13**: 662; 25 (deformation of lattice of metals). (<sup>39</sup>) Clark, Brugmann and Heath, *45*, **17**: 1142; 25 (ultimate structures of commercial metals). (<sup>40</sup>) Davey, *50*, **29**: 1211; 25 (plasticity of single crystals). (<sup>41</sup>) Elam, *115*, **120**: 368; 25 (orientation of crystals produced by heating strained Fe). (<sup>42</sup>) Fujiwara, *429*, **8A**: 339; 25 (arrangement of micro-crystals in Al-wire). (<sup>43</sup>) Glöcker, *96*, **31**: 386; 25 (deformation and recrystallization structures). (<sup>44</sup>) Glöcker, Kaupp and Widmann, *95*, **17**: 353; 25 (recrystallization of rolled plate Ag). (<sup>45</sup>) Leonhardt, *94*, **61**: 100; 25 (Laue diagrams of deformed crystals). (<sup>46</sup>) Lester and Aborn, *471*, **6**: 120, 200; 25 (Fe-crystals in steel under stress). (<sup>47</sup>) Mark, *94*, **61**: 75; 25 (growth and deformation structures). (<sup>48</sup>) Norton and Anderson, *2*, **25**: 582; 25 (cold-worked and burnished metals). (<sup>49</sup>) Ono, *470*, **3**: 195; 25 (Cu and Al under extension, compression and torsion). (<sup>50</sup>) Ono, *470*, **3**: 267; 25 ( $\alpha$ -Fe plastically strained in extension, compression and torsion). (<sup>51</sup>) Ono, *470*, **3**: 287; 25 (crystal rearrangement and the cause of strain-hardening). (<sup>52</sup>) Polanyi, *95*, **17**: 94; 25 (crystal deformation



and hardening). <sup>(53)</sup> Polanyi, *94*, **61**: 49; 25 (deformation of single crystals). <sup>(54)</sup> Polanyi and Schmid, *96*, **32**: 684; 25 (solidification and melting of Sn). <sup>(55)</sup> Sachs and Schiebold, *98*, **69**: 1557, 1601; 25 (volume compression of Al). <sup>(56)</sup> Sachs and Schiebold, *218*, **13**: 964; 25 (lattice lengths of deformed single crystals and crystal aggregates). <sup>(57)</sup> Seidl and Schiebold, *95*, **17**: 221, 320, 365; 25 (inhomogeneous Al-castings on cold rolling). <sup>(58)</sup> Tanaka, *429*, **8A**: 319; 25 (rolled Pt-plate). <sup>(59)</sup> Taylor and Elam, *5*, **108**: 28; 25 (plastic extension and fracture of Al-crystals).

<sup>(60)</sup> Carpenter, *440*, **28**: 543, 575; 26. **29**: 31, 26 (single crystals). <sup>(61)</sup> Elam, *5*, **112**: 289; 26 (tensile tests of large Au, Ag and Cu-crystals). <sup>(62)</sup> Frölich, Clark and Aborn, *Mass. Inst. Tech. Publications*, **61**: 239; 26. **78**, **49**: preprint; 26 (lead deposits). <sup>(63)</sup> Owen and Preston, *67*, **38**: 132; 26 (effect of rolling on crystal structure of Al). <sup>(64)</sup> Schiebold and Sachs, *94*, **63**: 34; 26 (growth of Al-crystals during recrystallization). <sup>(65)</sup> Smithells, Rooksby and Pitkin, *47*, **1926**: advance paper (deformation of W-crystals).

## V. ORIENTATION OF CRYSTALS IN ELECTRODEPOSITED METALS

<sup>(1)</sup> Glöcker and Kaupp, *96*, **24**: 121; 24 (fibrous structure). <sup>(2)</sup> Clark and Frölich, *9*, **31**: 655; 25 (electrolytic Ni). <sup>(3)</sup> Bozorth, *2*, **26**: 390; 25 (orientation of crystals in electrodeposited metals).

## VI. FIBROUS OR DEFORMED SUBSTANCES

<sup>(1)</sup> Friedrich, *63*, **14**: 317; 13 (X-ray interference in non-crystalline bodies). <sup>(2)</sup> Nishikawa and Ono, *219*, **7**: 131; 13 (transmission of X-rays through fibrous, lamellar and granular substances). <sup>(3)</sup> Nishikawa, *219*, **7**: 296; 14 (spectrum of X-rays obtained by lamellar or fibrous substances). <sup>(4)</sup> Becker, Herzog, Jancke and Polanyi, *96*, **5**: 61; 21 (arrangement of crystal elements). <sup>(5)</sup> Herzog, *218*, **12**: 955; 24 (fine structure of fibrous materials). <sup>(6)</sup> Rinne, *94*, **59**: 230; 24 (rearrangement and decomposition of crystal structures). <sup>(7)</sup> Rinne, *189*, No. **17**: 513; 24 (permanent structural deformation of graphite). <sup>(8)</sup> Schmid, *96*, **22**: 328; 24 (plastic deformation of crystals). <sup>(9)</sup> Rinne, *189*, **1925**: 225 (optical anomalies). <sup>(10)</sup> Rinne, *218*, **13**: 690; 25 (paracrystalline and stressed substances). <sup>(11)</sup> Rinne, *94*, **61**: 389; 25 (flow of natural salts). <sup>(12)</sup> Sachs and Schiebold, *95*, **17**: 400; 25 (melting and recrystallization). <sup>(13)</sup> Herzog, *472*, **24**: 137; 26 (fibrous substances). <sup>(14)</sup> Levitskii, *96*, **35**: 850; 26 (bending of rock-salt in air and water). <sup>(15)</sup> Ranzi, *59*, **3**, No. **3**: 135; 26 (changes in reticular distances of rock-salt and calcite).

## VII. CELLULOSE AND RELATED COMPOUNDS

<sup>(1)</sup> Herzog and Jancke, *96*, **3**: 196; 20 (cellulose). <sup>(2)</sup> Herzog, Jancke and Polanyi, *96*, **3**: 343; 20 (cellulose). <sup>(3)</sup> Herzog, *473*, **2**: 101; 21 (cellulose). <sup>(4)</sup> Herzog and Jancke, *92*, **34**: 385; 21 (cellulose). <sup>(5)</sup> Herzog, *472*, **21**: 388; 23 (deformation of cellulose). <sup>(6)</sup> Hess, Weltzien and Messmer, *13*, **435**: 1; 23 (cellulose). <sup>(7)</sup> Sponsler, *223*, **5**: 757; 23 (structural units of starch). <sup>(8)</sup> Gonell, *96*, **25**: 118; 24 (cellulose). <sup>(9)</sup> Katz, *63*, **25**: 659; 24 (X-ray spectroscopy and swelling). <sup>(10)</sup> Katz, *63*, **25**: 321; 24 (swelling of substances giving fibrous diagram). <sup>(11)</sup> Katz, *63*, **25**: 659; 24 (X-ray methods and imbibition). <sup>(12)</sup> Katz and Mark, *64V*, **33**: 294; 24 (swelling). <sup>(13)</sup> Sponsler, *2*, **23**: 662; 24 (X-ray reflection from very thin crystals). <sup>(14)</sup> Vieweg, *25*, **57B**: 1917; 24 (aqueous and dilute alcoholic NaOH and cellulose). <sup>(15)</sup> Herzog, *473*, **6**: 39; 25 (constitution of cellulose). <sup>(16)</sup> Herzog, *472*, **23**: 121; 25 (significance of fine structure of cellulose fiber in purification process). <sup>(17)</sup> Katz, *473*, **6**: 37; 25 (celluloses of different degrees of polymerization). <sup>(18)</sup> Katz, *473*, **6**: 35; 25 (X-ray data and alkali adsorption of cellulose). <sup>(19)</sup> Katz and Mark, *9*, **31**: 105; 25 (X-ray diffraction patterns of cellulose hydrate and its reversion products). <sup>(20)</sup> Katz and Mark, *7*, **115**: 385; 25 (changes in powder pattern of cellulose due to swelling). <sup>(21)</sup> Katz and Vieweg, *9*, **31**: 157; 25 (X-ray diffraction patterns and the alkali content during swelling of cellulose). <sup>(22)</sup> Herzog, *37*, **9**: 631; 26 (acetyl- and nitro-cellulose). <sup>(23)</sup> Herzog, *Pulp Paper Mag. Can.*, **24**: 699; 26 (colloidal characters of cellulose). <sup>(24)</sup> Herzog, *55*, **39**: 98; 26 (swelling of cellulose). <sup>(25)</sup> Herzog, *Pulp Paper Mag. Can.*, **24**: 694; 26. *Paper Trade J.*, **83**, No. **1**: 51; 26 (cellulose). <sup>(26)</sup> Herzog, *50*, **30**: 457; 26 (significance of structure of cellulose in chemical transformation). <sup>(27)</sup> Herzog and Gonell, *92*, **39**: 380; 26 (weighting of silk). <sup>(28)</sup> Katz, *9*, **32**: 269; 26 (inflation and mercerization of cellulose). <sup>(29)</sup> Ott, *37*, **9**: 378; 26 (crystalline character of acetyl-cellulose).

## VIII. RUBBER AND RELATED COMPOUNDS

<sup>(1)</sup> Davey, *2*, **21**: 719; 23 (ZnO in vulcanized rubber). <sup>(2)</sup> Pummerer, Koch and Gross, *13*, **438**: 294; 24 (crystalline rubber and hydorrubber). <sup>(3)</sup> Hauser and Mark, *Kautschuk*, Dec., 1925 (elongated samples of rubber). <sup>(4)</sup> Katz, *55*, **36**: 300; 25. **37**: 19; 25. **218**, **30**: 410; 25 (changing of X-ray spectrum of rubber on stretching). <sup>(5)</sup> Katz, *136*, **49**: 353; 25 (rubber under different degrees of elongation). <sup>(6)</sup> Katz and Bing, *92*, **38**: 439; 25 (Is raw rubber partially crystallized?). <sup>(7)</sup> Katz and Bing, *92*, **38**: 545; 25 (rubbers containing inorganic ingredients). <sup>(8)</sup> Clark, *45*, **18**: 1131; 26 (rubber and allied materials). <sup>(9)</sup> Hauser, *456*, **40**: 2090; 26 (origin of interference in stretching of rubber).

<sup>(10)</sup> Hauser and Mark, *287*, **Ambronn-Festschrift**: 64: 26 (stretched rubber). <sup>(11)</sup> Hauser and Mark, *287*, **22**: 63; 26 (stretched rubber). <sup>(12)</sup> Ott, *218*, **14**: 320; 26 (size of rubber and gutta-percha molecules).

## IX. CERAMIC MATERIALS AND PRODUCTS

<sup>(1)</sup> Hadding, *Lunds Universitets Årsskrift*, **14**: No. 23; 18. *Mineral. Abstr.*, **2**: 205 (feldspar). <sup>(2)</sup> Hadding, *Lunds Universitets Årsskrift*, **17**: No. 6; 20 (feldspar). <sup>(3)</sup> Kozu and Endö, *159*, **1 III**: 1; 21 (andularia and moonstone). <sup>(4)</sup> Bragg, Shearer and Mellor, *82*, **22**: 105; 23 (china clays). <sup>(5)</sup> Schwarz and Brenner, *25*, **56B**: 1433; 23 (synthetic aluminum silicate). <sup>(6)</sup> Rinne, *218*, **12**: 244; 24 (lead-pencil marks). <sup>(7)</sup> Schwarz, *105*, **8**: 298; 24. *103*, **32**: 538; 24 (formation of kaolin). <sup>(8)</sup> Shearer, *82*, **23**: 314; 24 (china clays). <sup>(9)</sup> Sielakov, *74B*, **21**: 527; 24 (clays). <sup>(10)</sup> Hadding, *82*, **24**: 27; 25 (clays). <sup>(11)</sup> Research Staff of General Electric Co., *82*, **24**: 402; 25 (constitutional changes occurring in clays on heating). <sup>(12)</sup> Navias, *38*, **8**: 296; 25 (development of mullite in fired clays). <sup>(13)</sup> Navias and Davey, *38*, **8**: 640; 25 (mullite and sillimanite). <sup>(14)</sup> Norton, *38*, **8**: 401; 25 (natural and artificial sillimanite). <sup>(15)</sup> Norton, *38*, **8**: 636; 25 (cyanite and andalusite). <sup>(16)</sup> Rinne, *103*, **33**: 427, 459, 525; 25 (X-ray and ceramics). <sup>(17)</sup> Rinne, *94*, **61**: 113; 25 (calcined calcite, dolomite, kaolinite and mica). <sup>(18)</sup> Bowen and Wyckoff, *128*, **16**: 178; 26 (thermal dissociation of dumortierite). <sup>(19)</sup> Greig, *38*, **8**: 465; 25. *12*, **11**: 1; 26 (mullite from cyanite, andalusite and sillimanite). <sup>(20)</sup> Mark and Rosbaud, *190B*, **54**: 127; 26 (Al<sub>2</sub>SiO<sub>5</sub> and pseudobrookite). <sup>(21)</sup> Rosbaud, *9*, **32**: 317; 26 (aluminum silicate). <sup>(22)</sup> Wyckoff, Greig and Bowen, *12*, **11**: 459; 26 (mullite and sillimanite).

## X. GLASS AND SILICA

<sup>(1)</sup> Kyropoulos, *93*, **99**: 197, 249; 17 (various kinds of silica). <sup>(2)</sup> Miller, *5*, **101**: 515; 22 (vitreous silica). <sup>(3)</sup> Washburn and Navias, *197*, **8**: 1; 22 (chalcedony and other forms of silica). <sup>(4)</sup> Selyakov and Strutinskii, *Mitt. wiss.-tech. Arbeiten in der Republik (Russ.)*, **13**: 18; 24 (structure of glass). <sup>(5)</sup> Selyakov, Strutinskii and Krasnikov, *96*, **33**: 53; 25 (structure of glass). <sup>(6)</sup> Wyckoff and Morey, *105*, **9**: 256; 25 (soda-lime-silica glasses).

## XI. X-RAY DATA APPLIED TO PROBLEMS OF CATALYSIS

<sup>(1)</sup> Clark, Asbury and Wick, *1*, **47**: 2661; 25 (structure of nickel catalysts). <sup>(2)</sup> Levi, *22*, **2**: 419; 25 (thorium oxide and the dehydration of alcohol). <sup>(3)</sup> Wyckoff and Crittenden, *1*, **47**: 2866; 25 (ammonia catalysts). <sup>(4)</sup> Levi and Haardt, *36*, **56**: 424; 26 (catalytic action considered as that of surfaces). <sup>(5)</sup> Levi and Haardt, *22*, **3**: 91; 26 (catalytic action of metals of the Pt group). <sup>(6)</sup> Levi and Haardt, *22*, **3**: 215; 26 (catalytic action of metals of the Pt group).

## XII. AMORPHOUS AND COLLOIDAL MATERIALS

<sup>(1)</sup> Asahara, *210*, **1**: 23; 22. *209*, **1**: 35; 22 (graphite and amorphous C). <sup>(2)</sup> Haber, *25*, **55B**: 1717; 22 (amorphous precipitates and crystallized sols). <sup>(3)</sup> Kustner, *96*, **10**: 41; 22 (decomposition and rebuilding of gadolinites). <sup>(4)</sup> Mulligan, *50*, **26**: 247; 22 (dehydration of crystalline aluminum hydroxide). <sup>(5)</sup> Böhm and Niclassen, *93*, **132**: 1; 23 (amorphous precipitates and crystallized sols). <sup>(6)</sup> Fricke and Wever, *93*, **136**: 321; 24 (aging of precipitated metal hydroxides). <sup>(7)</sup> Rinne, *94*, **60**: 55; 24 (finely divided minerals, artificial products and dense rocks). <sup>(8)</sup> Baudisch and Welo, *141*, **64**: 753; 25 (aging of ferrous hydroxide and ferrous carbonate). <sup>(9)</sup> Böhm, *93*, **149**: 203; 25 (aluminum hydroxide and iron hydroxide). <sup>(10)</sup> Böhm, *93*, **149**: 217; 25 (glowing of oxides of certain metals). <sup>(11)</sup> Herzog, *55*, **37**: 355; 25 (colloid systems). <sup>(12)</sup> Herzog and Gonell, *25*, **58B**: 2228; 25 (collagen). <sup>(13)</sup> Katz and Gerngross, *218*, **13**: 900; 25 (gelatin and collagen). <sup>(14)</sup> Levi, *216*, **7**: 410; 25 (new chemical studies). <sup>(15)</sup> Ruff, Schmidt and Olbrich, *93*, **148**: 313; 25 (amorphous C and graphite). <sup>(16)</sup> Welo and Baudisch, *141*, **65**: 215; 25 (catalytically active and inactive forms of Fe<sub>2</sub>O<sub>3</sub>). <sup>(17)</sup> Welo and Baudisch, *166*, **62**: 311; 25 (oxides of iron in new catalytic actions). <sup>(18)</sup> Gutbier, Hüttig and Dobling, *25*, **59B**: 1232; 26 (stannic oxide-water). <sup>(19)</sup> Herzog and Krüger, *218*, **14**: 599; 26 (dispersibility of organic colloids). <sup>(20)</sup> Posnjak, *50*, **30**: 1073; 26 (stannic acids).

## XIII. APPLICATION TO THE IDENTIFICATION OF COMPOUNDS

<sup>(1)</sup> Posnjak and Merwin, *1*, **44**: 1965; 22 (Fe<sub>2</sub>O<sub>3</sub>-SO<sub>3</sub>-H<sub>2</sub>O). <sup>(2)</sup> Schleede and Gruhl, *9*, **29**: 411; 23 (luminescent zinc silicate). <sup>(3)</sup> Kohlschütter and Scherrer, *37*, **7**: 337; 24 (polymorphism in lead oxide). <sup>(4)</sup> Levi and Quilico, *36*, **54**: 598; 24 (non-existence of Ag suboxide). <sup>(5)</sup> Shaxby, *34*, **179**: 1602; 24 (monochromatic X-rays in production of Laue diagrams and structure of mother-of-pearl). <sup>(6)</sup> Volmer, *13*, **440**: 200; 24 (HClO<sub>4</sub>.H<sub>2</sub>O and NH<sub>4</sub>ClO<sub>4</sub>). <sup>(7)</sup> Jung, *93*, **142**: 73; 25 (dehydration products of gypsum). <sup>(8)</sup> Levi, *216*, **7**: 410; 25 (new chemical studies). <sup>(9)</sup> Levi and Tacchini, *36*, **55**: 28; 25 (non-existence of Ni suboxide). <sup>(10)</sup> Linck and Jung, *93*, **147**: 288; 25 (black metallic P). <sup>(11)</sup> Shaxby, *3*, **49**: 1201; 25 (monochromatic X-rays in production of Laue diagrams and structure of mother-of-pearl). <sup>(12)</sup> Sosman and Posnjak, *128*, **15**: 329; 25 (ferromagnetic ferric oxide). <sup>(13)</sup> Ewles, *Proc. Leeds Phil. Lit. Soc.*, **1**: 6; 26 (luminescence of solids). <sup>(14)</sup> Fröbold, *187*, **23**: 115; 26 (iron hydroxide ores).



# PROPERTIES OF METALS AND ALLOYS

W. ROSENHAIN, SPECIAL EDITOR

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## INTRODUCTION

The very condensed form in which it has been necessary to present the metallurgical data in the tables, requires some explanation in regard to their use. The abbreviations and special symbols used are explained on p. 392 and some examples illustrating their interpretation in particular cases are given below.

A table of "Critical Values" of the mechanical properties of metals and alloys necessarily differs in certain important respects from the "Critical Values" given in other connections. The reason is that metallurgical products, particularly of the more complex sort, are subject to certain unavoidable variations even when produced under the best conditions. In regard to

## INTRODUCTION

Etant donné la forme très condensée dans laquelle il a été nécessaire de présenter les données métallurgiques dans les tables, il est indispensable de donner quelques explications pour leur emploi. Les abréviations et les symboles spéciaux utilisés sont expliqués à la p. 392, et quelques exemples illustrant leur interprétation dans des cas particuliers sont donnés ci-dessous.

Une table de "valeurs critiques" des propriétés mécaniques des métaux et alliages diffère nécessairement sous certains rapports importants des "valeurs critiques" données pour d'autres sujets. La raison en est que les produits métallurgiques, et plus particulièrement ceux qui sont les plus complexes, sont sujets à certaines varia-



<b>Mechanical Properties:</b> <b>Iron and Its Alloys</b>	<b>Propriétés mécaniques:</b> <b>Fer et ses alliages</b>	<b>Mechanische Eigenschaften:</b> <b>Eisen und seine Legierungen</b>	<b>Proprietà meccaniche:</b> <b>Ferro e sue leghe</b>
Fe, Fe-Co, Fe-Ti, and Ti-, and U-steels.	Fe, Fe-Co, Fe-Ti et aciers au Ti et à l'U.	Fe, Fe-Co, Fe-Ti, Ti- und U-Stähle.	Fe, Fe-Co, Fe-Ti, ed acciai al Ti ed all'U..... 478
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## EINLEITUNG

Die äusserst knappe Form in welcher die Metallurgie notwendigerweise in den Tafeln dargelegt ist, erfordert für ihren Gebrauch einige Erklärungen. Die vorkommenden Abkürzungen und besondere Symbole sind Seite 392 erklärt. Einige Beispiele zu ihrer Verständnis in besonderen Fällen sind weiter unten angegeben.

Eine Tafel der "Kritischen Werte" der mechanischen Eigenschaften von Metallen und Legierungen, weicht in gewissen wichtigen Beziehungen von den "Kritischen Werten" anderer Arten ab.

Dies ruht daher dass metallurgische Produkte, besonders solche komplexerer Art, gewissen unvermeidlichen Eigenschaftsschwank-

## INTRODUZIONE

La forma molto condensata in cui è stato necessario esporre i dati metallurgici richiede alcune spiegazioni circa l'uso delle tabelle. A pag. 392 sono spiegate le abbreviazioni e i simboli speciali adoperati, e più avanti sono riportati alcuni esempi illustranti la loro interpretazione in casi particolare.

Una tabella di "valori critici" delle proprietà meccaniche di metalli e leghe differisce necessariamente sotto alcuni punti di vista importanti dai "valori critici" di altre proprietà, e ciò per il fatto che i prodotti metallurgici, specie quelli più complessi, sono soggetti a variazioni inevitabili, anche se ottenuti nelle migliori condizioni. Per molti metalli e leghe i valori riportati



many of the metals and alloys mentioned in the tables the origin of the data varies widely, some being derived from numerous tests on industrial products, while others represent the results of laboratory investigation. In making use of the tables, therefore, it is necessary to ascertain the nature of the data given. This can always be done by reference to the literature quoted. While laboratory results are generally accurately determined, it must be borne in mind that they may be either higher or lower than the figures to be anticipated from a corresponding industrial product. In some instances large-scale production makes it possible to secure better results than can be obtained in relatively small laboratory experiments, while in other cases the special conditions which can be used in laboratory work cannot readily be reproduced in industrial production.

If it is desired to form an opinion of the value of a given material for constructional purposes the nature of the material must be considered. In the case of castings, wide variations in mechanical properties occur as between different parts of the same casting, as between a large and small casting, and as between actual castings and test bars prepared either at the same time or otherwise. Even in a casting of given shape and material, variations in casting conditions, such as pouring temperature, rate of pouring and mold temperature, may cause considerable differences in mechanical properties. The figures quoted in the tables must therefore be regarded as indicating the values found for cast materials under conditions specified in the corresponding literature, and cannot be used, without further consideration, for the purpose of calculating the reliable strength of a particular casting. In wrought material, variations are likely to be much smaller than in cast. However, complete uniformity cannot be relied upon, particularly as between the products of different makers. In regard to some materials which are extensively produced industrially, the data given in the tables sometimes represent the values obtained from very numerous tests. In other cases the data may represent only isolated experiments. In compiling the tables, care has been taken to incorporate as far as possible only the most reliable data of both kinds.

Another cause of considerable variation in the mechanical properties of metals and alloys, in the wrought state, arises from the effect of mass. Material in large sections is in almost every case weaker than the same material produced in small sections. This is particularly marked where heat treatment of any kind has been given. Where the data in the tables include values corresponding to materials of different sections, it will obviously be desirable to attach the greatest importance to those figures relating to materials which have a cross section similar to that which it is proposed to use, or whose properties it is desired to ascertain. It should also be borne in mind that there is a steady improvement in foundry, rolling mill, forging and heat-treating practice, so that, as a rule, the more modern methods yield values superior to those of older materials.

In the use of the tables three possibilities will arise: (I) The properties of an alloy whose composition is known are desired. (II) The properties of some commercial alloy whose composition is not known are desired. (III) An alloy having certain properties is desired.

#### I. Composition of Alloy Known. Properties Desired

1. Turn to the Table of Contents (p. 358), and ascertain the section in which this type of alloy is treated.

2. Turn to the section at the page number given.

3. With the aid of the Table of Contents at the beginning of the section, ascertain the table containing the desired type of information and turn to it.

4. In each table (unless otherwise indicated) the alloys are arranged in the order of their "type formulae." The type formula

tions inévitables, même lorsqu'ils ont été fabriqués dans les meilleures conditions. L'origine des données se rapportant à plusieurs des métaux et alliages mentionnés dans les tables varie dans une large mesure; certaines données proviennent de nombreux essais sur des produits industriels alors que les autres représentent les résultats d'expériences de laboratoire. C'est pourquoi il est nécessaire pour l'emploi des tables de s'assurer de la nature des valeurs données. Ceci peut toujours être réalisé en se référant à la source bibliographique citée. Les résultats de laboratoire sont généralement déterminée avec précision; il ne faut pas cependant perdre de vue qu'ils peuvent être ou supérieurs ou inférieurs aux chiffres qu'on peut attendre d'un produit industriel correspondant. Dans certains cas une production sur une large échelle permet l'obtention de meilleurs résultats que ceux qui peuvent être obtenus dans des expériences effectuées dans le laboratoire, alors que dans d'autres cas, les conditions spéciales qui peuvent être utilisées dans le travail de laboratoire ne sont pas reproductibles facilement dans une production industrielle.

Si l'on désire se faire une opinion de la valeur d'une matière donnée et cela pour des buts de construction, il faut considérer la nature de la matière. Dans le cas des pièces fondues, il existe de grandes variations dans les propriétés mécaniques aussi bien entre les différentes parties d'une pièce donnée qu'entre une grande ou une petite pièce ou qu'entre une pièce donnée et des éprouvettes préparées au même moment ou plus tard. Même pour une pièce de dimension et d'une matière données, les variations dans les conditions de coulée, telle que la température de coulée, la vitesse de coulée et la température du moule, peuvent occasionner des différences considérables dans les propriétés mécaniques. Les chiffres cités dans les tables doivent donc être regardés comme indiquant les valeurs trouvées pour des matières coulées dans des conditions spécifiées dans la littérature correspondante, et ils ne peuvent être utilisés sans autres considérations, dans le but de calculer une valeur de résistance digne de confiance d'une pièce coulée particulière. Dans les matières travaillées, les variations sont ordinairement plus petites que dans les matières fondues. Cependant, on ne peut pas tabler sur une complète uniformité, surtout entre des produits de différents fabricants. En ce qui concerne certaines matières qui sont produites industriellement en grand, les valeurs données dans les tables représentent quelquefois les valeurs obtenues dans de très nombreux essais. Dans d'autres cas, les valeurs peuvent ne représenter que des expériences isolées. En établissant les tables, il a été pris soin de n'incorporer autant que possible que les valeurs des deux sortes les plus dignes de confiance.

Une autre cause, occasionnant une variation considérable dans les propriétés mécaniques des métaux et alliages à l'état travaillé, est produite par l'effet de la masse. Une matière de grande section est dans presque chaque cas plus faible que la même matière produite en petites sections. Ce fait est particulièrement marqué lorsqu'un traitement thermique quel qu'il soit a été effectué. Lorsque les données dans les tables comportent des valeurs correspondant à des matières de différentes sections, il sera évidemment préférable d'attacher la plus grande importance aux chiffres se rapportant aux matières ayant une section similaire à celle qu'on se propose d'utiliser, ou dont on désire connaître les propriétés. Il ne faut pas oublier non plus qu'il se produit une amélioration certaine dans les opérations de fonderie, de laminage, de forgeage et par les traitements thermiques de sorte qu'en règle générale, les méthodes les plus modernes conduisent à des valeurs supérieures à celles obtenues avec des matières fabriquées moins récemment.

Trois possibilités se présentent dans l'usage des tables: (I) On désire connaître les propriétés d'un alliage, dont la composition est connue. (II) On désire connaître les propriétés d'un alliage commercial dont la composition n'est pas connue. (III) On



ungen unterworfen sind, selbst wenn die Herstellungsbedingungen die besten waren. Bezüglich der vielen in den Tabellen angeführten Metallen und Legierungen, sind die Quellen aus welchen die Daten entnommen worden sind, sehr verschieden. Einige Daten sind von vielen Materialsprüfungen an Industrie-Produkten abgeleitet, andere wieder, stellen das Ergebnis von Laboratoriumsuntersuchungen dar. Beim Gebrauche der Tafeln ist daher die Feststellung der Natur der Daten notwendig, was immer an Hand der angegebenen Literatur geschehen kann. Während im allgemeinen die Laboratoriumsergebnisse genau sind, muss man bedenken, dass die Zahlenwerte bald höher bald niedriger sein können als die, welche an einem Industrie-Produkt zu erwarten sind. In mancher Hinsicht gestattet die Herstellung im Grossen, ein besseres Ergebnis als es in dem verhältnismässig kleinem Masstab des Laboratoriums möglich ist. In anderen Fällen wieder können die Bedingungen im Laboratorium nicht leicht bei der industriellen Herstellung eingehalten werden.

Ist es wünschenswert, dass man sich ein Bild über die Zahlenwerte eines gegebenen Materials für Konstruktionszwecke macht, so ist es notwendig die Natur des Materials zu berücksichtigen. Beim Guss weichen die mechanischen Eigenschaften sehr weitgehend an verschiedenen Stellen desselben Gusstückes von einander ab. Unterschiede sind sowohl zwischen einem in grossen oder kleinem Gusstück als auch zwischen dem Hauptguss und dem Probestück vorhanden, wenn beide zugleich oder auf andere Weise hergestellt wurden. Sogar beim Giessen einer gegebenen Form und gegebenen Material, zeigen sich bemerkenswerte Differenzen der mechanischen Eigenschaften, wenn die Bedingungen beim Gusse, wie Gusstemperatur, Gussgeschwindigkeit, die Temperatur der Form, u. s. w., verändert werden. Es gelten daher die in den Tafeln angegebenen Zahlenwerte für ein gegossen hergestelltes Material nur unter den Bedingungen, welche in der entsprechenden Literatur angegeben sind. Die Zahlenwerte können jedoch nicht ohne weiteres zu dem Zwecke benützt werden, um einen zuverlässigen Eigenschaftswert eines bestimmten Gusses zu berechnen. In bearbeitetem Material sind die Unterschiede häufiger viel kleiner als im gegossenen. Auf eine vollkommene Gleichheit ist nie zu rechnen, ganz besonders bei Materialien verschiedenen Ursprunges. In Bezug auf gewisse Materialien, welche ausgedehnt industriell hergestellt werden, stellen die angegebenen Werte manchmal die Ergebnisse sehr zahlreicher Prüfungen dar. In manchen anderen Fällen beziehen sich die Daten nur auf einzelne Untersuchungen. Bei der Zusammenstellung der Tafeln wurden soweit als möglich sorgfältig nur die verlässlichsten Daten, beider Typen aufgenommen.

Ein anderer Grund zur Änderung der mechanischen Eigenschaften von Metall und Legierung im bearbeiteten Zustand, kommt vom Einfluss der Masse her. Ein Material in grossen Stücken ist fast in allen Fällen weicher, als wenn dasselbe in kleineren Stücken hergestellt wird. Dies ist besonders bei einer Wärmebehandlung irgend welcher Art hervortretend. Wo in den Tafeln Werte vorhanden sind die sich auf Material-Stücke verschiedener Grösse beziehen, so wird es natürlich wünschenswert sein die grösste Wichtigkeit den Zahlen beizulegen, die sich auf ein herausgearbeitetes Stück beziehen, welches gleich dem Stück ist, welches benützt werden soll, oder dem Stück dessen Eigenschaften man kennen lernen will.

Man bedenke, dass in den Giessereien, Walzwerken, bei der Schmiedung und Wärmebehandlung ständig Fortschritte zu verzeichnen sind, so dass in der Regel die modernere Methoden ein Material liefern, dessen Eigenschafts-Werte den nach älteren Methoden hergestellten überlegen sind.

Beim Gebrauch der Tabellen können drei Möglichkeiten vorliegen: (I) Man sucht Eigenschaften einer Legierung bekannter Zusammensetzung. (II) Man sucht Eigenschaften einer

proviengono da fonti notevolmente diverse: alcuni sono ricavati da numerosi saggi su prodotti industriali, mentre altri sono dedotti da ricerche di laboratorio. Nel servirsi delle tabelle è perciò necessario tener conto della natura dei dati, cosa che può sempre farsi riferendosi alla letteratura citata. I risultati di prove di laboratorio sono in genere accurati, e perciò essi possono essere più bassi o più alti dei valori prevedibili per un prodotto industriale corrispondente. In alcuni casi la produzione su larga scala rende possibile migliori risultati di quelli ottenibili in piccole prove di laboratorio, mentre in altri casi le condizioni speciali che si possono realizzare in laboratorio non si possono facilmente riprodurre nell'industria.

Per farsi una idea di un dato materiale a scopi costruttivi, se ne deve prendere in considerazione la natura. Nel caso di getti, ad es., si hanno ampie oscillazioni nelle proprietà meccaniche tra le diverse parti di uno stesso getto, come pure tra un getto grande e uno piccolo ed anche tra getti e provini, sia che questi vengano preparati assieme al getto sia che vengano ottenuti diversamente. Anche in un getto di forma e materiale determinati, eventuali differenze nelle condizioni di colata, come temperatura e velocità di colata, e temperatura della forma, possono produrre differenze notevoli nelle proprietà meccaniche. Perciò i valori delle tabelle indicano le proprietà del materiale quando questo sia ottenuto nelle condizioni specificate nella letteratura corrispondente ed essi non possono servire per calcolare senz'altro la resistenza probabile di un particolare getto. Nei materiali lavorati le variazioni sono spesso molto più piccole che in quelli ottenuti di getto; tuttavia non si può fare affidamento sopra una completa uniformità specie se si tratta di prodotti che hanno provenienza diversa. Per certi materiali che sono prodotti largamente nell'industria, i valori delle tabelle sono alcune volte ricavati da numerosissimi saggi; in altri casi invece essi rappresentano soltanto esperienze isolate. Nel compilare le tabelle si è avuto cura di servirsi il più che possibile solo dei valori dei due tipi che più sono degni di fiducia.

Considerevoli differenze nelle proprietà meccaniche dei metalli o leghe allo stato lavorato possono essere prodotti da effetto di massa. Un materiale in sezioni grandi è quasi sempre più debole che in sezioni piccole, e questo è particolarmente evidente nei casi in cui si è ricorso ad un trattamento termico qualunque. Quando nelle tabelle sono riportati valori corrispondenti a sezioni differenti, bisogna evidentemente attribuire la massima importanza ai numeri che si riferiscono a materiali con sezione simile a quella che si ha in animo di usare o di cui si vogliono stabilire le proprietà. Deve pure tenersi presente che vi è un continuo miglioramento nella pratica di fonderia di laminatoio, di fucina, e dei trattamenti termici per modo che, di regola, i metodi più moderni danno valori superiori a quelli dei materiali più antichi.

Nel servirsi delle tabelle tre casi si possono presentare: (I) Si può desiderare di conoscere le proprietà di una lega di cui è nota la composizione. (II) Si può desiderare di conoscere le proprietà di una lega commerciale di cui non è nota la composizione. (III) Si può desiderare di conoscere una lega che abbia determinate proprietà.

#### I. La composizione della lega è nota e si desidera conoscerne le proprietà

1. Si consulta l'indice a p. 358 e si vede quale è il capitolo in cui si parla di questo tipo di leghe.

2. Si consulta il capitolo alla pagina indicata.

3. Dall'indice che si trova al principio del capitolo si ricava la tabella che contiene il tipo di informazione che si desidera.

4. In ogni tabella (tranne che non sia indicato diversamente) le leghe sono disposte nell'ordine delle loro formule tipo. La formula tipo di una lega è costituita da dei simboli chimici dei suoi costituenti essenziali scritti in ordine decrescente della proporzione



of an alloy consists of the chemical symbols of its essential constituents written in descending order of their amounts in the alloy except in the case of steels, where C is written last. (*N. B.*—An element once thought merely incidental or an impurity in an alloy may later be found to have an important effect on its properties; cf. the case of silicon in duralumin.) Thus Pb-Sb-Cu is the type formula of alloys whose largest constituent (by weight) is Pb, the next largest Sb, and the next Cu; while a vanadium steel has the type formula Fe-V-C, although C is generally present in larger amounts than V. The different alloys are arranged in alphabetical order according to their type formulae.

Under a given type formula the alloys are arranged in descending order of the amounts of the principal constituent in the alloy, where this is given by analysis, and, where it is not given, then in ascending order of amounts of the second largest constituent in the alloy. Under each composition the data follow approximately in order of the extent of treatment given the alloy. Thus the properties of castings (symbol = G) appear first, then those of hot-worked material, and finally those of cold-worked material. The properties of heat-treated material follow immediately after those of the material before heat treatment.

*Example 1:* It is desired to compare the mechanical properties of a sand-cast 10% aluminum bronze with those of the same alloy in which 3% of the Al is replaced by Fe. It is desired to ascertain the properties of the alloys at high temperatures. The first alloy, call it "A," has the type formula Cu-Al; the second, call it "B," has the type formula Cu-Al-Fe. Turning to the Table of Contents (p. 359), we find that the section containing the mechanical properties of Al bronzes, begins on p. 572. Turning here we find a Table of Contents for the section in which are listed 15 tables of properties of the type Cu-Al and 6 tables of properties of the type Cu-Al-Fe.

Let us first consider the Ultimate Tensile Strength (*UTS*) in kg/mm<sup>2</sup>, % Elongation (*El*) and Brinell Hardness Number (*BHN*) of our alloy "A" in the sand-cast (*G<sub>s</sub>*) condition. From the tables we find as follows:

Table	<i>t</i> , °C	<i>UTS</i>		<i>El</i>		<i>BHN</i>		Lit.
		20	500	20	500	20	500	
1		46-53		20		90-100		(13)
2		49.9		21.7				(3)
3		29.1	18.2	9.4	3.1			(2, 15)
4						76.7	<50	(12)
13		42.2		28.5		118		(26)
13		52.0		19.5		100		(7)

The values in Table 1 represent the average properties of alloy "A" and agree fairly well with those in the other tables excepting those in Table 3, which probably are for material cast under unsatisfactory conditions, a thing easily possible with aluminum bronze.

Considering alloy "B" in the same manner we have:

Table	<i>t</i> , °C	<i>UTS</i>		<i>El</i>		<i>BHN</i>		Lit.
		20	500	20	500	20	500	
17		52.4		38.0		80		(10)
20		(Contains 7.6% Al, 2% Fe)				125	70	(12)

Although fewer data are available, alloy "B" seems to be as strong as and more ductile than "A" at 20°C, while the presence of 2% Fe has increased the hardness of the alloy at 500°C. Hardness figures of (12), however, are inconsistent with those from other sources. On the basis of the tables then, alloy "B" is somewhat the better alloy.

The index (p. 370) shows whether any commercial alloys of the composition of "B" are included. Index numbers of aluminum bronzes are listed in one of the tables of Alloy Classes following

désire un alliage ayant certaines propriétés. Les trois cas seront considérés dans l'ordre indiqué.

#### I. Composition de l'alliage connue. Propriétés désirées

1. Consulter la table des matières p. 358 et s'informer de la section dans laquelle il est traité de ce type d'alliage.

2. Consulter cette section à la page indiquée.

3. Au moyen de la table des matières se trouvant au commencement de la section, s'informer qu'elle est la table contenant le type d'information désiré et s'y porter.

4. Dans chaque table (à moins d'une autre indication) les alliages sont arrangés dans l'ordre de leur "formule type." La formule type d'un alliage se compose des symboles chimiques de ses constituants essentiels écrits dans l'ordre descendant de leurs proportions dans l'alliage, excepté pour le cas des aciers, où C est écrit en dernier. (*N. B.* Il peut se trouver qu'un élément dont la présence peut être considérée accidentelle ou une impureté dans un alliage peuvent avoir un effet important sur ses propriétés: par ex. cas du silicium dans duralumin). Ainsi Pb-Sb-Cu est la formule type des alliages dont le constituant le plus important (en poids) est Pb, celui qui vient ensuite dans le même ordre d'idée est Sb, et finalement vient Cu; un acier au vanadium aura la formule type Fe-V-C, quoique C soit généralement présent en plus grande quantité que V. Les différents alliages sont arrangés dans l'ordre alphabétique en accord avec leurs formules types.

Sous une formule type donnée, les alliages sont arrangés, lorsque ce résultat est fourni par l'analyse, dans l'ordre descendant des proportions de leur constituant principal dans l'alliage; lorsque l'analyse n'a pas été effectué, dans l'ordre ascendant des proportions du deuxième constituant en importance de l'alliage. Sous chaque composition, les données suivent approximativement dans l'ordre de la succession des traitements subis par l'alliage. Ainsi les propriétés des pièces fondues (symbole = G), sont mentionnées en premier. Ensuite viennent les propriétés de la matière travaillée à chaud et finalement celles de la matière travaillée à froid. Les propriétés de la matière traitée thermiquement suivent immédiatement celles de la matière avant le traitement thermique.

*Exemple 1:* On désire comparer les propriétés mécaniques d'un bronze d'aluminium à 10% Al coulé en sable avec celles du même alliage dans lequel 3% de l'Al ont été remplacés par Fe. On désire connaître les propriétés des alliages à hautes températures. Le premier alliage, désignons-le par "A," a la formule type Cu-Al; le second, désignons-le par "B" a la formule type Cu-Al-Fe. Consultant la table des matières (p. 359) on trouve que la section contenant les propriétés mécaniques des bronzes d'Al commence à p. 572. À cette page nous trouvons une table des matières pour la section, dans laquelle sont disposées en liste 15 tables des propriétés du type d'alliage Cu-Al et 6 tables des propriétés du type d'alliage Cu-Al-Fe.

Considérons d'abord: la charge de rupture (*UTS*) en kg/mm<sup>2</sup>, l'allongement en % (*El*) et le nombre de dureté Brinell (*BHN*) de notre alliage "A" dans la condition "coulé en sable" (*G<sub>s</sub>*). Des tables, on trouve:

Table	<i>t</i> , °C	<i>UTS</i>		<i>El</i>		<i>BHN</i>		Lit.
		20	500	20	500	20	500	
1		46-53		20		90-100		(13)
2		49,9		21,7				(3)
3		29,1	18,2	9,4	3,1			(2, 15)
4						76,7	<50	(12)
13		42,2		28,5		118		(26)
13		52,0		19,5		100		(7)

Les valeurs dans la Table 1 représentent les propriétés moyennes de l'alliage "A," elles s'accordent assez bien avec celles des autres



Legierung des Handels, unbekannter Zusammensetzung. (III) Man sucht eine Legierung von bestimmten Eigenschaften.

#### I. Die Zusammensetzung der Legierung ist bekannt. Eigenschaften gesucht

1. Man sehe im Inhaltsverzeichnis (S. 358) nach und stelle den Abschnitt fest in welchem diese Legierungstypen behandelt wird.

2. Man schlage den Abschnitt an der gegebenen Seitenzahl auf.

3. Mit Hilfe des Inhaltsverzeichnisses am Anfang dieses Abschnittes, stelle man die Tafel fest, welche die gewünschte Typen der Eigenschaften enthält und schlage diese Tafel dann auf.

4. In jeder Tafel (wenn nichts anderes angegeben ist) sind die Legierungen in der Reihenfolge ihrer "Typen-Formel" angeordnet. Diese "Typen-Formel" einer Legierung besteht in der Nebeneinandersetzung der chemischen Zeichen ihrer wesentlichen Bestandteile in absteigender Ordnung ihrer Prozentgehalte. Eine Ausnahme ist bei den Stählen vorhanden, wo am Ende C steht. (N. B.—Ein Element, das zuweilen nur zufällig oder als Verunreinigung in den Legierungen vorhanden angesehen wurde, kann später als ein solches von besonderem Einfluss auf die Eigenschaft derselben erkannt werden, z. B. Si in Duralumin.) So ist Pb-Sb-Cu die Typenformel von Legierungen, in welchen Pb den höchsten Prozentgehalt darstellt, den nächst niedrigeren Sb, dann folgt Cu. Ein Vanadium-Stahl hat hingegen die Typenformel Fe-V-C, obwohl im allgemeinen C in grösserer Menge als V vorhanden ist. Die verschiedenen Legierungen sind in alphabetischer Reihenfolge ihrer Typenformeln angeordnet.

Unter einer gegebenen Typenformel sind die Legierungen in absteigender Ordnung des analytisch bekannten Hauptbestandteiles in der Legierung angeordnet. Ist dieser Gehalt nicht bekannt, so sind die Legierungen in aufsteigender Ordnung des Prozentgehaltes des zweiten grössten Bestandteiles angeordnet. Unter jeder Zusammensetzung folgen die Daten ungefähr nach der Zahl der verschiedenen Behandlungen, welchen die Legierung unterworfen wurde. So erscheinen die Eigenschaften des Gusses (Zeichen = G) zuerst, dann jene des heiss bearbeiteten und zum Schluss des kalt bearbeiteten Materials. Die Eigenschaften des wärmebehandelten Materials folgen unmittelbar nach denen des Materials vor der Wärmebehandlung.

**Beispiel 1:** Es sollen die mechanischen Eigenschaften einer in Sandform gegossenen 10% Aluminiumbronze mit einer gleichen Legierung verglichen werden, in welcher 3% des Aluminiumgehaltes durch Fe ersetzt sind. Die Kenntnis der Eigenschaften bei hoher Temperatur ist notwendig. Die erste Legierung, wir bezeichnen sie mit "A," hat die Typenformel Cu-Al, die zweite, "B" bezeichnet, hat die Typenformel Cu-Al-Fe. Aus dem Inhaltsverzeichnis (S. 359) finden wir, dass der Abschnitt, welcher die mechanischen Eigenschaften der Al-Bronzen enthält, auf S. 572 beginnt. Hier finden wir ein Inhaltsverzeichnis für diesen Abschnitt in welchem 15 Eigenschafts-Tafeln der Type Cu-Al und 6 Eigenschafts-Tafeln für die Type Cu-Al-Fe, vorhanden sind.

Wir wollen zuerst von der Legierung "A" (in Sandform gegossen) die Zugfestigkeit (UTS) in kg/mm<sup>2</sup>, Prozent Dehnung (El) und die Brinell-Härtezahl (BHN) berücksichtigen. Aus den Tafeln finden wir:

Tabelle	UTS		El		BHN		Lit.
	20	500	20	500	20	500	
1	46-53		20		90-100		(13)
2	49,9		21,7				(3)
3	29,1	18,2	9,4	3,1			(2, 15)
4					76,7	<50	(12)
13	42,2		28,5		118		(26)
13	52,0		19,5		100		(7)

in cui sono contenuti, eccetto nel caso degli acciai, dove C è scritto per ultimo. (N. B. Un elemento ritenuto solo accidentale oppure giudicato come impurezza può in seguito trovarsi che ha un effetto importante sulle proprietà di una lega: vedi, ad es. il caso del silicio nel duralluminio.) Così Pb-Sb-Cu è la formula tipo delle leghe nelle quali la proporzione maggiore in peso è di Pb, quella intermedia è di Sb e quella minore è di Cu; mentre un acciaio al vanadio ha la formula Fe-V-C, sebbene C, in genere, è presente in proporzione maggiore di V. Le diverse leghe sono disposte in ordine alfabetico secondo le loro formule tipo.

Sotto una certa formula tipo le leghe sono disposte in ordine decrescente della proporzione del costituente principale quando questa è nota. Se questa non è nota esse sono disposte nell'ordine crescente del contenuto del secondo componente più abbondante. Sotto ogni composizione i dati sono disposti approssimativamente nell'ordine della complessità del trattamento. Così le proprietà dei getti (simbolo = G) vengono per prime, poi quelle del materiale lavorato a caldo, e infine quelle del materiale lavorato a freddo. Le proprietà del materiale trattato a caldo seguono subito dopo quelle del materiale prima del trattamento a caldo.

**Esempio 1:** Si desideri confrontare le proprietà meccaniche di un bronzo d'alluminio al 10% colato in sabbia, con quelle della stessa lega nella quale 3% di alluminio è stato sostituito con ferro, e precisamente si desideri conoscere le proprietà della lega a temperature elevate. La prima lega, che indicheremo con "A," ha la formula tipo Cu-Al; la seconda, che indicheremo con "B," ha la formula tipo Cu-Al-Fe. Se si consulta l'indice (p. 359) si trova che il capitolo contenente le proprietà meccaniche dei bronzi di alluminio comincia a p. 572. Qui si trova un indice in cui sono riportate 15 tabelle di proprietà per il tipo Cu-Al e 6 tabelle di proprietà per il tipo Cu-Al-Fe.

Consideriamo dapprima il carico di rottura (UTS) in kg/mm<sup>2</sup>, l'allungamento per cento (El) e il numero di durezza Brinell (BHN) della lega "A" colata in sabbia (G<sub>s</sub>). Dalle tabelle si trova:

Tabe a	t, °C	UTS		El		BHN		Lit.
		20	500	20	500	20	500	
1		46-53		20		90-100		(13)
2		49,9		21,7				(3)
3		29,1	18,2	9,4	3,1			(2, 15)
4						76,7	—50	(12)
13		42,2		28,5		118		(26)
13		52,0		19,5		100		(7)

I valori della Tabella 1 rappresentano le proprietà medie della lega "A" e si accordano bene con quelli delle altre tabelle; si eccettuano solo i valori della Tabella 3, che probabilmente si riferiscono ad un materiale gettato in condizioni non soddisfacenti, cosa questa è facilmente possibile con i bronzi d'alluminio.

Se si considera la lega "B" allo stesso modo si ha:

Tabella	t, °C	UTS		El		BHN		Lit.
		20	500	20	500	20	300	
17		52,4		38,0		80		(10)
20		(7,6% Al, 2% Fe)				125	70	(12)

Sebbene si disponga di pochi dati, la lega "B" sembra sia resistente quanto la "A" e persino più duttile della "A" a 20°C, mentre la presenza del 2% di ferro ha accresciuto la durezza a 500°C. I numeri di durezza riportati nella (12) non si accordano però con quelli di altre fonti. In base alle tabelle tuttavia la lega "B" è un po' migliore.

Dall'indice (p. 370) si può sapere se nelle tabelle sono riportate leghe commerciali della composizione di "B." I numeri indici dei



the Finding Index. Turning to these numbers in the Finding Index, we find No. 45, "Alcumite:" Cu; Al, 7.5; Fe, 5.5; Ni, Mn, No. 141, "Ampeco bronze:" Cu; Al, 7-11; Fe, 1-5. If the alloys thus shown in the Finding Table are commercially available at the present time, reference to the firms producing them can no doubt be obtained from the advertising pages of metallurgical magazines or otherwise. It must, however, be borne in mind that other alloys, possibly of the type desired, are manufactured in various countries, without necessarily being known by a name which could be included in the Finding Index, while there are numerous manufacturers in every country having a well-developed metallurgical industry, who will be prepared to make up alloys to any desired specification, provided that patent rights do not interfere. In some instances, it may be noted that the properties of the materials as represented by data given in the corresponding table, can only be obtained by definitely stated methods of manufacture and treatment and these are, sometimes, available only at the hands of an individual manufacturing firm. Further, where alloys having trade names are given in the list, and if no definite data for these alloys as such are included, the inference that the alloy bearing the trade name will have the same properties as the alloy of similar composition listed in the detailed table, must be regarded as subject to the limitations just indicated.

*Example 2:* Given a Ni-Cr steel containing 3.5% Ni, 0.8% Cr and 0.25% C, to find the heat treatment giving the optimum combinations of tensile and notched-bar impact properties. From the Table of Contents, it is found that Ni-Cr steels are treated in the section beginning on p. 483. The first numbered table of this section is a table of compositions, in which No. 262 is found to correspond to the above composition. The table of contents at the beginning of the section (p. 483) shows that mechanical properties are given in Table 7, p. 510. Turning to this table, we locate alloy No. 262 (p. 511) and find that values of properties are given for 42 different conditions of this steel. Notched-bar impact test results are given under the following designations:  $IS_u$  (Izod machine using B. E. S. A. standard specimen),  $IS_v$  (Charpy machine using 45° V notch specimen),  $IS_x$  (Guillery machine, Mesnager notch). The energy absorbed in fracture is given in each case as there is no satisfactory basis for comparison of results as between the different types of specimen. The largest Izod values of No. 262 are for treatments h, j, k, and z, being respectively 8.85, 9.15, 9.0, and 9.0. Of these, "h" gives a material somewhat stronger and considerably more ductile than do the others. Meanings of symbols and abbreviations used in describing treatments are given in the table on p. 392. Treatment "h" reads as it stands "Same, Tp 650° Q<sub>w</sub>." The "Same" refers to the previous treatment, *i.e.*, condition before tempering, which is N 820°. The whole treatment interpreted is: Normalized at 820° (*i.e.*, cooled in still air from 820°C), then tempered at 650°C and quenched in water. The other treatments which give high impact strengths, are: "1000° Q<sub>o</sub> Tp 670°/120 Q<sub>w</sub>" (*i.e.*, quenched in oil from 1000°C, tempered at 670° for 120 min, and quenched in water); "1000° Q<sub>o</sub> Tp 650°/120 C<sub>s</sub> 650° Q<sub>w</sub>" (*i.e.*, quenched in oil from 1000°C, tempered at 650° for 120 min, cooled slowly, retempered at 650°C and quenched in water); and "850° Q<sub>o</sub> Tp 675°/495 Q<sub>w</sub>" (*i.e.*, quenched in oil from 850°C, tempered at 675° for 495 min, and quenched in water). These treatments give nearly as good properties, thus showing the necessity of a final water quench from 650-675°C. Consideration of some of the other treatments shows that cooling slowly from this temperature gives decidedly inferior notched-bar impact figures while not greatly affecting the tensile values. Quenching from lower temperatures gives better tensile properties, but inferior notched-bar impact figures. Inspection of values obtained on the other machines for these treatments and for others

tables excepté celles de la Table 3, qui se rapportent probablement à un matériel fondu dans les conditions non satisfaisantes, une circonstance qui est très possible avec le bronze d'aluminium.

Considérant l'alliage "B" de la même manière, nous avons:

t, °C Table	UTS		El		BIIN		Lit.
	20	500	20	500	20	300	
17	52,4		38,0		80		(10)
20	(7.6 % Al, 2 % Fe)				125	70	(12)

Quoiqu'il y ait peu de données disponibles, l'alliage "B" paraît être aussi résistant et plus ductile que "A" à 20°C, alors que la présence de 2 % de Fe a augmenté la dureté de l'alliage à 500°C. Les chiffres de dureté de (12) cependant, ne sont pas en accord avec ceux d'autres sources. On peut déduire sur la base des tables que l'alliage "B" est sensiblement le meilleur alliage.

L'index (p. 370) montre s'il y existe un alliage commercial de la composition de "B." Les nombres index des bronzes d'aluminium sont disposés en liste dans l'une des tables des alliages types qui se trouvent à la suite de l'index de recherche. En se reportant à ces nombres dans l'index de recherche, on trouve N° 45, "Alcumite:" Cu; Al, 7.5; Fe, 5.5; Ni; Mn, et N° 141, "Ampeco bronze:" Cu; Al, 7-11; Fe, 1-5. Si les alliages ainsi mentionnés dans la table de recherche sont disponibles dans le commerce actuellement, on trouvera sans doute les références des firmes qui les produisent dans les annonces des magazines métallurgiques ou autre part. Il ne faut pas oublier cependant que d'autres alliages, qui peuvent être du type désiré sont fabriqués dans des pays divers, sans être nécessairement connus par un nom qui pourrait se trouver dans l'index de recherche; il existe en effet de nombreux fabricants dans chaque pays possédant une industrie métallurgique bien développée qui peuvent fabriquer des alliages suivant les spécifications variées, à condition que les droits de patente ne s'y opposent pas. Dans certains cas, il faut remarquer que les propriétés des matières ainsi qu'elles sont représentées par les valeurs données dans les tables correspondantes, ne peuvent être obtenues que par des méthodes de fabrication et des traitements établis d'une façon définie, qui quelquefois ne sont réalisés que chez un seul fabricant. Lorsqu'il s'agit d'alliages portant des noms commerciaux mentionnés dans la liste, il n'a pas été indiqué de données définies pour ces alliages considérés comme tels, et, déduire que les alliages portant un nom commercial ont les mêmes propriétés que l'alliage de composition similaire mentionné dans la table détaillée, doit être regardé comme étant sujet aux limitations indiquées ci-dessus.

*Exemple 2:* Etant donné un acier au Ni-Cr contenant 3,5 % Ni, 0,8 % Cr et 0,25 % C, trouver le traitement thermique donnant la combinaison optimum relativement aux propriétés de traction et à l'essai de choc sur éprouvette entaillée. De la table des matières, on trouve que les aciers au Ni-Cr sont traités dans la section commençant à p. 483. La première table de cette section est une table de compositions, dans laquelle le N° 262 correspond à la composition donnée ci-dessus. La table des matières au commencement de la section (p. 483) montre que les propriétés mécaniques sont données dans la Table 7, p. 510; à cette table nous trouvons l'alliage N° 262 (p. 511) et constatons que les valeurs des propriétés sont données pour 42 différentes conditions de cet acier. Les résultats concernant l'essai de choc sur éprouvette entaillée sont donnés sous les désignations suivantes:  $IS_u$  (Machine d'Izod, utilisant des éprouvettes types B. E. S. A.),  $IS_v$  (Machine de Charpy utilisant une éprouvette avec entaille 45°V),  $IS_x$  (Machine de Guillery, éprouvette avec entaille Mesnager). L'énergie absorbée dans la rupture est donnée dans chaque cas, car il n'existe pas de base convenable pour la comparaison des résultats entre les différents types d'éprouvettes. Les valeurs Izod les plus fortes concernant le N° 262 sont obtenues avec les traitements



Der Wert in der Tabelle 1 stellt die Durchschnittseigenschaften der Legierung "A" dar, und stimmt ziemlich gut mit jenen in den anderen Tabellen überein. Ausgenommen jedoch die Werte der Tabelle 3, welche wahrscheinlich für ein Material gelten, das unter nicht befriedigenden Bedingungen gegossen worden ist. Bei Aluminiumbronzen ist ein solcher Fall sehr möglich. Nehmen wir die Legierung "B," so hat man in gleicher Weise:

Tabelle	$t, ^\circ\text{C}$	UTS		El		BHN		Lit.
		20	500	20	500	20	500	
17		52,4		38,0		80		(10)
20		(7.6% Al, 2% Fe)				125	70	(12)

Obgleich weniger Daten vorliegen, scheint die Legierung "B" bezüglich der Zugfestigkeit ebenso gut wie "A," bezüglich der Duktilität bei 20° besser zu sein, während die Anwesenheit von 2% Fe die Härte bei 500°C erhöht. Die Härtezahlen von (12) aber stimmen mit denen aus anderen Quellen stammenden nicht überein. Auf Grund der Tafeln ist "B" eine etwas bessere Legierung als "A."

Der Index (S. 370) zeigt an, ob irgend eine Handelslegierung von der "B" Zusammensetzung gegeben ist. Die Indexzahlen der Aluminiumbronzen sind in einer der Tafeln für Legierungstypen eingetragen, die dem Nachschlage-Index folgen. Sehen wir diese Zahlen im Nachschlage-Index nach, so finden wir No. 45, "Alcumite:" Cu; Al, 7,5; Fe, 5,5; Ni, Mn; No. 141, "Ampeo bronze:" Cu; Al, 7-11; Fe, 1-5. Sind diese Legierungen gegenwärtig handelsüblich, so kann vermutlich die Erzeugerfirma in dem Inseratenteil der Fachzeitschriften und auch sonst, gefunden werden. Es muss jedoch berücksichtigt werden, dass andere Legierungen, möglicherweise gerade von der gewünschten Type, in den verschiedenen Ländern erzeugt werden können, die vielleicht keinen Namen tragen, der in dem Nachschlage-Index angegeben werden konnte. Es gibt in jedem Lande mit einer gut entwickelten Metallindustrie, eine Anzahl von Fabriken die imstande sind, soweit nicht Patentrechte vorliegen, jede Legierung von besonderer Zusammensetzung herzustellen.

Es möge noch bemerkt werden, dass in mancher Beziehung, die in den entsprechenden Tabellen angegebenen Eigenschaften nur durch bestimmte Fabrikations-Methoden und Behandlungen erreicht werden können, die zuweilen nur den einzelnen Erzeugerfirmen zur Verfügung stehen. Ferner, wo in den Tabellen Legierungen mit Handelsmarken angegeben sind und keine definitive Werte für solche in den Tafeln angeführt sind, ist eine Schlussfolgerung, wie aus dem Vorhergegangenen folgt, dass eine Legierung mit Handelsmarke dieselben Eigenschaften habe als eine ähnlich zusammengesetzte Legierung die sich in der Tabelle vorfindet, sehr einzuschränken.

*Beispiel 2:* Gegeben ist ein Ni-Cr-Stahl mit 3,5% Ni, 0,8% Cr, und 0,25% C. Es ist die Wärmebehandlung zu finden, die ein Optimum an Zugfestigkeit und Schlagfestigkeit an einem gekerbten Probestück gibt. Aus dem Inhaltsverzeichnis findet man, dass Ni-Cr-Stähle in dem S. 483 beginnenden Abschnitt behandelt werden. Die erste Zahlentafel dieses Abschnittes gibt die Zusammensetzungen an worunter No. 262, der angegebenen Zusammensetzung entspricht. Das Inhaltsverzeichnis zu Beginn des Abschnittes (S. 483) gibt an, dass die mechanischen Eigenschaften in der Tafel 7, S. 510, zu finden sind. Hier findet man die Legierung No. 262 (S. 511) und sieht, dass die Eigenschaften für 42 verschiedene Behandlungen für diese Stahlsorte vorliegen. Die Schlagfestigkeit (Kerbeneinschnitt) ist unter der folgenden Bezeichnung angegeben:  $IS_u$  (Izod Machine, B. E. S. A. standard Probe),  $IS_v$  (Charpy-Machine, mit 45° V-Kerbe),  $IS_x$  (Guillery Machine, Kerbenformstück nach Mesnager). Die beim Bruch absorbierte Energie ist in jedem Falle angegeben, da keine befriedi-

bronzi di alluminio sono elencati in una delle tabelle dei tipi di leghe che seguono l'indice. Andando a cercare questi numeri nell'indice, si trova No. 45, "Alcumite:" Cu; Al, 7,5; Fe, 5,5; Ni; Mn; e No. 141, "Ampeo Bronze:" Cu; Al, 7-11; Fe, 1-5. Se le leghe così indicate si trovano in commercio, si può sapere il nome delle ditte che le producono dalla *réclame* delle riviste metallurgiche o in qualche altro modo. Può darsi però che nei diversi paesi vengano fabbricate altre leghe, e che esse non siano conosciute con un nome che potrebbe essere incluso nell'indice. In ogni nazione con una industria metallurgica bene sviluppata, vi è un gran numero di produttori i quali sono in grado di fabbricare leghe con qualsiasi requisito purché non esistano diritti di brevetti. Deve ancora osservarsi che le proprietà, quali sono rappresentate dai valori contenuti nelle tabelle, in alcuni casi possono solo ottenersi con processi di fabbricazione e trattamento ben definiti, e che questi talvolta sono a conoscenza esclusiva di una singola ditta fabbricante. Inoltre, quando nell'elenco sono contenute leghe con nomi commerciali, nessun valore definito è riportato per esse, e la deduzione che la lega con quel certo nome avrà le stesse proprietà di quella di composizione simile elencata nella tabella deve considerarsi sottoposta alle limitazioni sopraindicate.

*Esempio 2:* Dato un acciaio al Ni-Cr contenente 3,5% Ni, 0,8% Cr e 0,25% C, trovare qual'è il trattamento termico che dà l'optimum di carico di rottura e di resilienza. Nell'indice si trova che gli acciai al Ni-Cr sono trattati nel capitolo che comincia a p. 483. La prima tabella di questo dà le composizioni, e in essa si trova che il numero 262 corrisponde alla composizione di sopra. Dall'indice all'inizio del capitolo (p. 483) si ricava che le proprietà meccaniche sono esposte nella Tabella 7 (p. 510). Consultando questa si vede che a p. 511 sono riportati valori delle proprietà per 42 condizioni differenti dell'acciaio No. 262. I risultati delle prove di resilienza sono riportati sotto le seguenti designazioni:  $IS_u$  (macchina Izod con provino B.E.S.A.),  $IS_v$  (macchina Charpy con provino munito di intaglio V a 45°),  $IS_x$  (macchina Guillery con barretta Mesnager). L'energia assorbita nella rottura è data per ogni caso, giacché non vi son elementi sufficienti per confrontare i risultati ottenuti con i diversi tipi di prove. I più grandi valori Izod del numero 262 sono per i trattamenti h, j, k, e z, e sono rispettivamente 8,85; 9,15; 9,0 e 9,0. Fra essi, "h" dà un materiale un po' più resistente e notevolmente più duttile che gli altri. I significati dei simboli e le abbreviazioni adoperate nel descrivere i trattamenti sono indicati nella tabella a p. 392. Il trattamento "h" è indicato con "Same, Tp 650° Q<sub>w</sub>." Il "Same" (lo stesso) si riferisce al trattamento precedente, e cioè alla condizione prima del rinvenimento, che è N 820°. L'intero trattamento perciò è normalizzato a 820° (e cioè raffreddato in aria calma a partire da 820°C), quindi rinvenuto a 650° e temprato in acqua. Gli altri trattamenti che danno resilienza elevata sono "1000° Q<sub>o</sub> Tp 670°/120 Q<sub>w</sub>" (e cioè temprato in olio a partire da 1000°C, rinvenuto a 670° per 120 min, e temprato in acqua; "1000° Q<sub>o</sub> Tp 650°/120 C<sub>s</sub> 650° Q<sub>w</sub>" (cioè temprato in olio a partire da 1000°C, rinvenuto a 650° per 120 min, raffreddato lentamente, rinvenuto di nuovo a 650°C e temprato in acqua; e "850° Q<sub>o</sub> Tp 675°/495 Q<sub>w</sub>" (cioè temprato in olio a partire da 850°C, rinvenuto a 675° per 495 min, e temprato in acqua). Questi trattamenti danno tutti quasi le stesse buone proprietà e mostrano così la necessità di una tempra finale in acqua a partire da 650-675°C. Se si considerano alcuni altri trattamenti, si vede che il raffreddamento lento a partire da questa temperatura dà valori di resilienza decisamente inferiori, anche se non influenza molto i valori del carico di rottura. La tempra a partire da temperature più basse dà proprietà tensorie migliori, ma valori di resilienza più bassi. L'esame dei valori ottenuti per questi trattamenti e per altri per i quali non sono dati valori Izod, mostra che il trattamento "h" dà l'optimum dei valori desiderati.



for which no Izod values are given, show that treatment "h" gives the optimum desired values.

## II. Name of Alloy Is Known, Its Composition and Properties Are Desired

Refer to the Finding Index, p. 370. The first column of this index contains the Index Numbers by which commercial alloys are identified when their properties occur in the tables. The second column contains 1510 trade names of alloys included in the following classes:

- (a) Trade mark names of patented alloys, as "Alpax."
- (b) Trade mark names of alloys no longer protected by patent (cf. Duralumin in France, where name "Aldal" is used for an alloy of approximately the same composition, the name Duralumin being protected).
- (c) Names of inventor or manufacturer given to alloys, the names or compositions not necessarily being protected, as Babbitt metal.
- (d) Names generally applied to certain types of alloys, as Cartridge Brass.
- (e) Names of types of alloys including a wide range of compositions, as Chrome Nickel steel. In this case, particular alloys of this type may be found from Tables of Alloy Classes, p. 388.
- (f) Designations of standard or tentative standard alloys, and certain government-specification alloys. These will be found under the alloy type as: Brass ingots, A. S. T. M. Spec. B30-22 or Government Bronze, Spec. G.

No distinction is made in the Finding Index among the first four classes, except that in some cases it has been necessary to identify an alloy, known usually by a number, by adding the manufacturer's name, as in the case of alloy No. 193 of the Driver Harris Co. This is listed under Ferronickel, but cross-reference is given to this and similar alloys under "Numbered Alloys." In other cases the manufacturer is not mentioned.

In class (d) no attempt has been made to include all alloys to which usage has given a name, as Spring Steel, Dynamo Sheets, etc., although such alloys are useful for the purpose indicated.

With regard to class (f) it should be mentioned that specifications may be drawn up regardless of existing patents and, of course, in ignorance of pending ones.

The names of alloys are arranged alphabetically regardless of type, excepting in the case of: (1) Alloys known by a manufacturer's number. (2) Specification alloys known by number or letter. (3) Alloys, the first part of whose name is descriptive of condition (e.g., hard solder), where there are several such included in one type. Such alloys are listed under the name of the type and where commonly used, cross-references are also given under first part of name.

The third column of the Finding Index gives the compositions of the alloys. In stating the composition, the elements together with their weights % are given in descending order of amounts in the alloy. Where the % of the first, i.e., largest constituent, is not given, it has not been determined by analysis. Where the amounts of the last constituents are not given, they are only incidental or impurities. Where no percentages are given, the information has not been available.

Where the composition of an alloy varies over a range of values, the limits have been stated, as Index No. 915, MS steel: Fe; Cr, 0.8-1.1; Mo, 0.3-0.4; Mn, 0.6-0.9; C, 0.4-0.6.

The fourth column of the Finding Index contains the page numbers where values of properties of the alloy may be found; the page numbers where the values of properties of a similar alloy may be found are indicated by italic type.

The electrical, magnetic and optical properties of metals and alloys will be found in a succeeding volume of I. C. T.; no page reference to such data can therefore be given in the Finding Index.

h, j, k et z, et sont respectivement 8,85, 9,15, 9,0 et 9,0. Parmi ceux-ci, "h" donne une matière un peu plus résistante et considérablement plus ductile que les autres. La signification des symboles et les abréviations utilisées pour spécifier les traitements sont données dans la table à la p. 392. Le traitement "h" représente "Same, Tp 650° Q<sub>w</sub>," "Same" (c'est-à-dire le même) se rapporte au traitement antérieur, c'est-à-dire, à la condition avant le revenu, qui est N 820°. L'interprétation de tout le traitement est la suivante: Normalisé à 820° (c'est à dire refroidi dans l'air calme à partir de 820°C), ensuite revenu à 650° puis trempé à l'eau. Les autres traitements qui donnent une grande résistance au choc sont: "1000° Q<sub>o</sub> Tp 670°/120 Q<sub>w</sub>" (c'est à dire, trempé à l'huile à partir de 1000°C, revenu à 670° pendant 120 minutes, refroidi doucement, de nouveau revenu à 650°C et trempé à l'eau); et "850° Q<sub>o</sub> Tp 675°/495 Q<sub>w</sub>" (c'est-à-dire trempé à l'huile à partir de 850°C, revenu à 675°C pendant 495 min. et trempé à l'eau). Ces traitements donnent tous à peu près d'aussi bonnes propriétés montrant ainsi la nécessité d'une trempe à l'eau finale à partir de 650-675°C. L'examen de quelques autres traitements montre que le refroidissement lent à partir de cette température donne décidément des chiffres inférieurs à l'essai de choc sur éprouvette entaillée tout en n'affectant pas beaucoup les valeurs de traction. Une trempe à partir de températures plus basses donne des meilleures propriétés à la traction, mais des chiffres inférieurs à l'essai de choc sur éprouvette entaillée. L'examen des valeurs obtenues sur les autres machines pour ces traitements et pour d'autres pour lesquels il n'a pas été donné de valeurs Izod montre que le traitement "h" donne l'optimum désiré.

## II. Le nom de l'alliage est connu; on désire connaître sa composition et ses propriétés

Consulter l'index de recherche, p. 370. La première colonne de cet index contient les nombres index au moyen desquels les alliages commerciaux sont identifiés lorsque leurs propriétés sont mentionnées dans les tables. La deuxième colonne contient 1510 noms commerciaux des alliages compris dans les classes suivantes:

- (a) Noms commerciaux d'alliages brevetés, comme "Alpax."
- (b) Noms commerciaux d'alliages dont le brevet est expiré; (par exemple: Duralumin en France, où le nom "Aldal" est utilisé pour un alliage ayant approximativement la même composition, le nom Duralumin étant déposé).
- (c) Noms de l'inventeur ou du fabricant donnés aux alliages, les noms ou les compositions n'étant pas nécessairement déposés, comme métal "Babbitt."
- (d) Noms généralement employés pour désigner certains types d'alliages, comme "Cartridge brass," laiton pour cartouches.
- (e) Noms de types d'alliages comportant un large intervalle de composition, comme acier en chrome nickel. Dans ce cas on peut trouver des alliages particuliers de ce type dans les "Tables of Alloy Classes," p. 388.
- (f) Désignation d'alliages standards ou alliages standards tentatifs et certains alliages suivant spécifications gouvernementales. Ceux-ci seront trouvés sous le type d'alliage comme par exemple: Brass ingots (laiton en lingots), A. S. T. M. Spec. B30-22 ou Bronze du Gouvernement, Spec. G.

Il n'a pas été fait de distinction dans l'index de recherche pour les quatre premières classes, excepté dans quelques cas où il a été nécessaire pour identifier un alliage connu ordinairement par un nombre, d'ajouter le nom du fabricant comme dans le cas de l'alliage N° 193 de la Driver Harris Co. Celui-ci est inscrit sous ferronickel, mais il y a une référence pour cet alliage et pour les alliages similaires sous "Numbered Alloys." Dans d'autres cas le fabricant n'est pas mentionné.

Dans la classe (d) on n'a pas cherché à inclure tous les alliages auxquels l'usage a donné un nom, tels que acier à ressorts, tôles



gende Basis zum Vergleich der Ergebnisse bei verschiedenen Typen der Proben vorhanden sind. Der höchste Izod-Wert für No. 262 ergibt sich für die Behandlung h, j, k und z, und beträgt der Reihe nach 8,85, 9,15, 9,0 und 9,0. Von diesen gibt "h" ein Material höherer Zugfestigkeit und ein deutlich duktileres Material als die anderen. Erklärungen der Zeichen und die Behandlung betreffenden Abkürzungen sind in der Tabelle S. 392 angegeben. Die Behandlung "h" ist durch "Same, Tp 650° Q<sub>w</sub>" in den Tafeln ausgedrückt. "Same" zeigt vorhergegangene Behandlung an, d. h. Zustand vor der Anlassung, welche "N 820°" ist. Die ganze Behandlung ist angezeigt: Normalisiert bei 820° (d. h. gekühlt in ruhender Luft von 820° herunter), dann bei 650°C angelassen und in Wasser abgeschreckt. Die anderen Behandlungen, welche eine sehr grosse Schlagfestigkeit geben, sind: 1000° Q<sub>o</sub> Tp 670°/120 Q<sub>w</sub> (d. h. bei 1000° in Öl abgeschreckt bei 670°, 120 Minuten lang angelassen und in Wasser abgeschreckt); "1000° Q<sub>o</sub> Tp 650°/120 C<sub>s</sub> 650° Q<sub>w</sub>" (bei 1000° in Öl abgeschreckt, für 120 Minuten lang bei 650° angelassen, langsam gekühlt, nochmals bei 650° angelassen und in Wasser abgeschreckt); ferner "850° Q<sub>o</sub> Tp 675°/495 Q<sub>w</sub>" (d. h. bei 850° in Öl abgeschreckt, 495 Minuten lang bei 675° angelassen, und in Wasser abgeschreckt). Diese Behandlungen geben ungefähr gleich gute Eigenschaften und zeigen die Notwendigkeit einer am Schlusse vorgenommenen Wasserabschreckung von 650–675°. Die Betrachtung einiger anderer Behandlungen zeigt, dass eine langsame Kühlung von dieser Temperatur herunter entschieden niedrigere Werte für die Schlagfestigkeit gibt, während die Zugfestigkeit und Duktilität nicht stark beeinflusst wird. Abschreckung bei tieferen Temperaturen gibt bessere Zugfestigkeit und Duktilität, aber niedrigere Werte für die Schlagfestigkeit. Eine Durchsicht der Werte die mit anderen Maschinen erhalten werden, zeigt für diese Behandlungen und andere, für welche keine Izod-Werte gegeben sind, dass die "h" Behandlung das Optimum der gewünschten Eigenschaft gibt.

## II. Der Name der Legierung ist bekannt, es sind ihre Zusammensetzung und Eigenschaften zu ermitteln

Siehe im Nachschlage-Index S. 370 nach. Die erste Kolonne in diesem enthält die Index-Zahl, durch welche Handelslegierungen bezeichnet sind, wenn ihre Eigenschaften in den Tabellen vorkommen. Die zweite Kolonne enthält 1510 Handelsnamen von Legierungen die in folgende Klassen eingeteilt sind.

(a) Handelsmarken patentierter Legierungen, wie z. B. "Alpax."

(b) Handelsmarken von Legierungen, nicht mehr unter Patentschutz stehend (vgl. Duralumin in Frankreich, wo der Name "Aldal" für eine Legierung von ungefähr derselben Zusammensetzung benützt wird, da der Name Duralumin geschützt ist).

(c) Die Legierung trägt den Namen des Erfinders oder des Erzeugers. Der Name selbst braucht nicht notwendig geschützt zu sein; z. B. Babbitt-Metall.

(d) Namen die im allgemeinen gewissen Legierungstypen gegeben werden; z. B. "Cartridge brass," Patronen-Messing.

(e) Namen von Legierungen deren Zusammensetzung in weitem Ausmasse variieren kann, z. B. Chrom-Nickel Stahl. In solchem Fall, die besondere Legierung dieser Type in "Tables of Alloy Classes," S. 388 zu finden ist.

(f) Als Standards bestimmte Legierungen oder solche als Prüfungs-Standard geltende, ferner gewisse staatlich vorgeschriebene Legierungen. Diese werden unter folgenden Legierungstypen gefunden: Brass ingots, A. S. T. M. Spec. B30–22 Government Bronze, Spec. G.

Es ist in den ersten vier Klassen kein Unterschied im Nachschlage-Index gemacht, ausgenommen, dass es in manchen Fällen notwendig war eine, sonst nur durch eine Zahl bekannte Legierung durch Hinzufügung des Namens des Fabrikants näher zu bezeichnen, z. B. bei der Legierung No. 193 der Driver

## II. Si suppone noto il nome della lega e si desidera conoscerne la composizione e le proprietà

Si consulti l'indice di ricerca a pag. 370. La prima colonna contiene i numeri indici con cui sono indicate le leghe commerciali, e la seconda 1510 nomi commerciali di leghe suddivisi nelle classi seguenti:

(a) Nomi commerciali di leghe brevettate, come "Alpax."

(b) Nomi commerciali di leghe non più protette da brevetti (ad es. in Francia si usa il nome "Aldal" per una lega che ha approssimativamente la stessa composizione del duralluminio, essendo il nome duralluminio protetto da brevetto).

(c) Nomi di inventori o fabbricanti dati alle leghe. I nomi o le composizioni non sempre sono protette da brevetti, come ad es. nel caso del metallo "Babbitt."

(d) Nomi generalmente applicati a certi tipi di leghe, come ad es. "Cartridge brass," ottone per cartucce.

(e) Nomi di tipi di leghe che possono avere composizioni oscillanti entro limiti larghi, come ad es. acciai al cromo-nichel. In questi casi, si possono trovare leghe particolari di detto tipo nelle "Tables of Alloy Classes," p. 388.

(f) Indicazioni di leghe standard, o tentativi standard, e di certe leghe con le caratteristiche richieste da amministrazioni governative. Queste si troveranno riportate sotto i tipi di leghe come: Brass ingots (lingotti di ottone), A. S. T. M. Spec. B30–22, oppure bronzo secondo le prescrizioni governative, Spec. 9.

Nessuna distinzione è fatta nell'indice tra le prime quattro classi eccetto che in alcuni casi è stato necessario aggiungere, al numero che ordinariamente contraddistingue una lega, il nome del fabbricante, come nel caso della lega N° 193 della Driver Harris Co. Questa è elencata tra i ferro-nichel, ma sotto "Numbered Alloys" vi è un rapporto a questa ed a leghe simili al N° 193. In altri casi non è fatta menzione del fabbricante.

Nella classe (d) non si è tentato di comprendervi tutte le leghe alle quali l'uso ha dato un nome, come acciaio per molle, lamierini per dinamo, ecc., sebbene dette leghe siano utili per gli scopi indicati.

Riguardo alla classe (f) deve ricordarsi che determinate caratteristiche possono ottenerli indipendentemente dal brevetti esistenti e, naturalmente, nell'ignoranza di eventuali in corso.

I nomi delle leghe sono disposti per ordine alfabetico senza tener conto del loro tipo tranne il caso di: (1) Leghe indicate con il numero di un fabbricante. (2) Leghe speciali note con un numero o una lettera. (3) Leghe di cui la prima parte del nome ne descrive la natura (per es. "hard solder," saldatura forte) quando ve ne sono parecchie comprese in uno stesso tipo. Tali leghe sono elencate sotto il nome del tipo, e, quando esse sono comunemente adoperate, si trovano riportate indicazioni anche sotto la prima parte del nome.

La terza colonna dell'indice dà le composizioni delle leghe. Nell'indicare la composizione, gli elementi e le rispettive percentuali sono date in ordine decrescente del contenuto nella lega. Quando il percento del primo costituente, e cioè quello più abbondante, non è indicato, significa che esso non è stato determinato con l'analisi. Quando le proporzioni degli ultimi componenti non sono indicate, essi sono soltanto costituenti accidentali o impurezze. Se le percentuali non sono riportate, significa che non si è potuto avere l'informazione relativa.

Quando la composizione di una lega può assumere tutta una serie di valori, sono stati indicati i limiti entro i quali i valori possono oscillare, come per es. per Index No. 915, MS steel: Fe; Cr, 0,8–1,1; Mo, 0,3–0,4; Mn, 0,6–0,9; C, 0,4–0,6.

Nella quarta colonna dell'indice sono indicate le pagine dove si possono trovare valori delle proprietà della lega (in caratteri romani) oppure dove si possono trovare i valori delle proprietà di una lega simile (in corsivo).

No data on resistance to corrosion are included in these tables. In the opinion of the most competent experts on the subject, it is not possible to give quantitative data for the corrosion resistance of metals and alloys. No page references can therefore be given in regard even to certain alloys which are chiefly valued on account of their resistance to corrosion. These, however, are listed in the tables of alloy types.

The sources of information for the Finding Index have been as follows: William Campbell's List of Names of Alloys, prepared for Committee B-2 of the A. S. T. M.; names and compositions given by the co-operating experts; and current metallurgical and technological literature.

### III. It Is Desired to Find an Alloy Having Certain Desired Properties

For this purpose consult the Table of Properties on p. 610, directions being given there.

de dynamo, etc., quoique de tels alliages soient utiles pour le but indiqué.

En ce qui concerne la classe (f), il faut mentionner que des spécifications peuvent être rédigées sans tenir compte des patentes existantes et naturellement aussi dans l'ignorance des brevets demandés.

Les noms des alliages sont disposés dans l'ordre alphabétique sans tenir compte de leur type, excepté dans les cas suivants: (1) Alliages connus par un numéro de fabrique. (2) Certains alliages connus par un nombre ou une lettre. (3) Alliages dont la première partie de leurs noms est descriptive de la condition (par ex. "hard solder," soudure dure) et où il existe plusieurs variétés incluses dans un type. De tels alliages sont inscrits sous le nom du type et lorsqu'ils sont d'un usage commun, sont aussi mentionnés dans l'index par la première partie de leur nom.

La troisième colonne de l'index de recherche donne les compositions des alliages. En établissant la composition, on a inscrit les éléments avec leurs poids en % successivement dans l'ordre des proportions décroissantes dans l'alliage. Lorsque le pourcentage du premier, c'est-à-dire le constituant principal, n'est pas donné, c'est qu'il n'a pas été déterminé par l'analyse. Lorsque les proportions des derniers constituants ne sont pas mentionnés, ceux-ci ne sont qu'accessoires ou bien sont des impuretés. Lorsqu'aucun pourcentage n'est donné, c'est que l'information n'a pas été disponible.

Lorsque la composition d'un alliage varie suivant un intervalle de valeurs, les limites ont été fixées: par ex. Index No. 915, MS steel: Fe; Cr, 0,8-1,1; Mo, 0,3-0,4; Mn, 0,6-0,9; C, 0,4-0,6.

La quatrième colonne de l'index de recherche contient en caractères romains les numéros des pages où l'on peut trouver les propriétés de l'alliage, ou en italique les numéros des pages, où l'on peut trouver les valeurs des propriétés d'un alliage similaire.

On trouvera les propriétés électriques, magnétiques et optiques des métaux et alliages dans un volume suivant des T. C. I.; on ne peut donc donner aucune page de référence pour de telles données dans l'index de recherche.

On ne trouvera dans ces tables aucune donnée relative à la résistance à la corrosion. D'après l'opinion des experts les plus compétents sur ce sujet, il n'est pas possible de donner des valeurs quantitatives pour la résistance à la corrosion des métaux et alliages. On ne peut donc donner aucune référence en ce qui concerne même certains alliages dont la valeur est surtout due à leur résistance à la corrosion. Ceux-ci, cependant sont mentionnés dans les tables des types d'alliages.

Les sources d'information pour l'index de recherche ont été les suivantes: List of Names of Alloys établie par William Campbell préparée pour le Comité B-2 de l'A. S. T. M.; noms et compositions données par les experts coopérants; et la littérature métallurgique et technologique courante.

### III. On désire trouver un alliage ayant certaines propriétés désirées

Pour cela, consulter la Table des Propriétés à la p. 610, où les instructions sont données.



Harris Co. Sie ist unter Ferronickel mit einem entsprechenden Hinweis angeführt, der dieser und ähnlichen Legierungen unter "Numbered Alloys" beigelegt wird.

Zu (d). Es ist nicht die Absicht gewesen, alle solche Legierungen hier zu vereinigen denen der Gebrauch besondere Namen, wie Feder-Stahl, Dynamo-Lamellen, u. s. w., beigelegt hat, obgleich diese Legierungen für die angezeigte Verwendung nützlich sind.

Hinsichtlich (f) wäre zu bemerken, dass die Vorschriften ohne Rücksicht auf vorhandene und in Unkenntnis angemeldeter Patente, niedergeschrieben werden können.

Die Namen der Legierungen sind in alphabetischer Reihenfolge ohne Rücksicht auf die Type angeordnet. Ausgenommen: (1) Die Legierung hat die Nummer eines Erzeugers. (2) Besondere Legierungen die durch eine Zahl oder Buchstaben kenntlich gemacht sind. (3) Legierungen in deren Namen der erste Teil ihre Natur beschreibt (z. B. "hard solder," hart Lot). Es sind dann mehrere in einer Type vereinigt. Solche Legierungen sind unter dem Namen der Type angeführt unter welcher sie gewöhnlich gebraucht werden. Unter dem ersten Teil der Namen sind Hinweisdaten gegeben.

Die dritte Kolonne des Nachschlage-Index enthält die Zusammensetzung der Legierungen. Die Elemente, welche die Zusammensetzung ausdrücken sind zusammen mit ihrem Prozentgehalt absteigend nach diesem, angeordnet. Ist der Prozentgehalt des Hauptbestandteiles nicht angegeben, so ist er analytisch nicht bestimmt. Sind die Mengen des letzten Bestandteiles nicht angegeben, so ist dieser nur zufällig vorhanden oder nur Verunreinigung. Fehlen der Prozentzahlen bedeutet, dass keine diesbezügliche Angaben erreichbar waren.

Ändert sich die Zusammensetzung einer Legierung innerhalb einer Grenze, so werden nur die Grenzwerte angegeben, z. B. Index No. 915, MS steel: Fe; Cr, 0,8-1,1; Mo, 0,3-0,4; Mn, 0,6-0,9; C, 0,4-0,6.

Die vierte Kolonne des Nachschlage-Index enthält die Seitenzahlen, wo die Werte für die Eigenschaften gefunden werden können. Die Eigenschaften ähnlicher Legierungen sind auf den kursiv gedruckten Seitenzahlen zu finden.

Die elektrischen, magnetischen und optischen Eigenschaften der Metalle und Legierungen sind Gegenstand späterer Bände der I. C. T. Aus diesem Grunde sind keine diesbezügliche Hinweise im Nachschlage-Index angegeben.

In den Tafeln finden sich keine Angaben über Korrosion. Nach der Meinung massgebender Fachleute ist es nicht möglich quantitative Angaben über den Widerstand gegen Korrosion zu machen. Es sind daher diesbezüglich keine Angaben vorhanden, selbst in Hinblick auf gewisse Legierungen die gerade wegen ihres Widerstandes gegen Korrosion besonders geschätzt werden. Sie sind aber unter den Legierungstypen zu finden.

Für den Nachschlage-Index sind folgende Quellen massgebend gewesen: William Campbell's List of Names of Alloys, prepared for Committee B-2 of the A. S. T. M.; Namen und Zusammensetzung wie sie von den Mitarbeitern (Experten) angegeben worden sind; die vorhandene metallurgische und technologische Literatur.

### III. Es ist eine Legierung mit gewünschten Eigenschaften aufzufinden

Zu diesem Zwecke benütze man die S. 610 vorhandenen Eigenschaftstafeln, wo weitere Richtlinien gegeben sind.

Le proprietà elettriche, magnetiche e ottiche dei metalli e delle leghe si troveranno in un volume successivo delle I. C. T.; non è possibile perciò fare richiami a questi valori nell'indice.

Dati sulla resistenza alla corrosione non sono inclusi nelle tabelle, giacchè, secondo i maggiori conoscitori dell'argomento, non è possibile indicare con dati quantitativi la resistenza alla corrosione. Valori numerici non sono perciò riportati neppure per certe leghe che sono soprattutto apprezzate per la loro resistenza alla corrosione. Esse tuttavia sono elencate nelle tabelle dei tipi di leghe.

Le fonti per la compilazione dell'indice sono state: William Campbell's List of Names of Alloys, preparato per il Comitato B-2 della A. S. T. M.; nomi e composizioni fornite dai collaboratori; la letteratura tecnologica e metallurgica corrente.

### III. Si desidera trovare una lega che abbia certe proprietà

A questo scopo si consulti la tabella delle proprietà a p. 616 dove si troveranno indicazioni in proposito.

## FINDING INDEX OF ALLOYS

Index No.	Name	Composition	Page	Index No.	Name	Composition	Page
1	A alloy (forging).....	Al, 77; Zn, 20; Cu, 3	538, 608	50	Al-Cu-Zn, strong (forged).....	Al, 75; Zn, 22; Cu, 3	537, 601
2	Abyssinian gold.....	Cu, 88; Zn, 11.5; Au, 0.5 (v. also Index No. 1371)		51	Alfénide.....	Nickel silver	
3	Accumulator metal.....	Pb, 90; Sn, 9.2; Sb, 0.8	467, 557	52	Alférium.....	Similar to Duriron	
4	Acid bessemer pig.....	Fe; C, 3.5-4; Si, 1-1.5; Mn, 0.5; P, $\geq 0.1$ ; S, $\geq 0.05$		53	Algiers (Alger's) metal.....	Sn, 95-75; Sb, 0.5-25; Cu, 5-0	476, 557
5	Acid bronze.....	Cu, 88-82; Sn, 8-10; Pb, 2-8; Zn, 2-0; P, 0-0.2	561, 562, 567	54	Alkali-resisting metal.....	Fe, 95; Ni, 5	481, 604
6	Acid bronze.....	Cu, 74; Pb, 17; Sn, 8; Zn, 1.5	561, 562	55	Allan red bronze.....	Cu, 70-55; Pb, 20-40; Sn, 10-5; S, 1	562
	Acid resisting alloys:	For list, v. p. 391		56	Allan red metal.....	Cu, 50; Pb, 50; S	562
7	.....	Pb, 52; Sn, 35; Sb, 8; Cu, 5	557		Alloy cast iron.....	v. Index Nos. 870 and 974	
8	.....	Cu, 83; Sn, 11; Zn, 6; Pb*	569		Alloy No.....	For certain alloys known by numbers, v. p. 381	
9	U. S. patent 1 333 706.....	Cr, 60; Fe, 39; C, 0.3-0.8			Alloy steels.....	For list, v. p. 390	
10	U. S. patent 1 375 081.....	Fe, 56; Cr, 40; Mo, 4; C, 1.5		57	Al-Ni-Ti.....	Al, 98; Ni, 2; Ti, 0.4	543
11	Can. patent 206 645.....	Ni, 46-38; Cu, 31-38; Fe, 16-20; Cr, 7-5; Mn, 0.3-0.8		58	Al-Ni-Zn.....	Al, 85; Ni, 10; Zn, 5	
12	Acid resisting steel (U. S. patent 1 391 450)	Fe, 86; Cr, 13; C, 0.3; Mn; Si; P; S	471, 472, 508, 603	59	Alpakka.....	Cu, 64; Zn, 19; Ni, 15; Ag, 2; Fe; Sn; Pb	475, 480
13	Acieral (cast).....	Al; Cu, 6; Ni, 1; Si, 0.4; Fe; Mg; Zn		60	Alpax (Pacz patents).....	Al; Si, 12-14; Fe, $\geq 0.8$ ; K, or Na, 0.05	468, 543, 599, 601
14	Acieral (sheet).....	Al; Cu, 2.3-3.8; Mn, 1-1.5; Fe, 0.7-1.4; Mg	534	61		Al; Si, 5-6; Fe, $\geq 1.0$ ; K, or Na, 0.05	468, 543, 601
15	Acme nickel steel.....	Fe; Ni, 30.5; Cr, 1.4-1.6; C, 0.3; Mn; Si; P; S		62	Aludur.....	Al; Si, 0.7; Mg, 0.5; Fe, 0.45; Cu	459, 475, 536, 601
16	Admiralty, A (Admiralty condenser tube, Admiralty metal)	Cu, 70; Zn, 29; Sn, 1	469, 556, 600	63	Aluman.....	Al, 88; Zn, 10; Cu, 2	468, 537
17	Admiralty brass.....	Cu, 62; Zn, 37; Sn, 1.4	470, 556	64	Alumel.....	Ni, 94; Mn, 2.5; Al, 2; Si, 1; Fe, 0.5	
18	Admiralty gun metal (Admiralty bronze).....	Cu, 88; Sn, 10; Zn, 2	476, 565	65	Aluminite (cast).....	Al, 73; Zn, 23; Cu, 2.7; Fe, 0.4; Si, 0.2	537, 601
19	Admiralty gun metal†.....	Cu, 88-86; Sn, 10; Zn, 1.1-1.5; Pb, 0.2-1.7; As, 0.5; Fe, 0.06-0.08	566, 567, 570-572		Aluminium alloys* known by letter or number:		
20	Admiralty white metal.....	Sn; Sb, 8-9; Cu, 2-7	476, 557		Aluminum Co. of America, casting alloys:		
21	Adnic (Admiralty nickel).....	Cu, 70; Ni, 29; Sn, 1	601	66	No. 12†.....	Al; Cu, 8; Fe, 0.5-1.75; Si, 0.3-0.5	
22	Advance.....	Cu, 54-55; Ni, 44-46; Mn, 0.8-1.2; Fe, 0.5	480, 601, 606	67	No. 31.....	Al, 82; Zn, 15; Cu, 3	459, 467, 475, 533, 534, 537-542, 601
23	Aerolite.....	Al, 97; Cu, 1.2; Fe, 1; Si, 0.5; Mg, 0.4; Zn	533	68	No. 43.....	Al; Si, 5; Fe, $\geq 1$	
24	Aerolite pistons.....	Al, 86; Cu, 12; Mn, 2	467, 534	69	No. 45.....	Al; Si, 10	
25	Aero metal (cast).....	Al, 67; Zn, 28; Cu, 4.2; Fe, 0.5; Si, 0.5	537	70	No. 47†.....	Al; Si, 12.5	
26	Aero metal (sheet).....	Al, 96; Mg, 2.1-2.9; Cu, 0.2-0.6; Fe; Mn; Si	464, 542	71	No. 100.....	Al, $\leq 99$	
27	Aeromin.....	Al; Mg, 6.2; Fe, 0.8; Si, 0.3	542, 608	72	No. 106.....	Al; Mn, 2	
28	Aeron (Scleron II).....	Al; etc., v. Scleron		73	No. 109.....	Al; Cu, 12.5	
29	Agrilite (No. 5).....	Cu, 70.5; Pb, 24; Sn, 5.4; Ni, 0.1; P, 0.005	561, 562, 567	74	No. 112.....	Al; Cu, 6-8; Zn, $\geq 2.5$ ; Fe, $\geq 1.5$	
30	Aich metal.....	Cu, 60; Zn, 38; Fe, 1.5	556	75	No. 145.....	Al; Zn, 10; Cu, 2.5; Fe, 1.25	
31	Air hardening steel (Key No. 267, p. 512)	Fe; Ni, 3.7-4.3; Cr, 1.4-1.6; Mn, 0.4; C, 0.3; Si; P; S	512, 513, 604	76	No. 195.....	Al; Cu, 4	
32	Ajax metal.....	Fe, 70-30; Ni, 25-50; Cu, 5-20			Aluminum Co. of America, wrought alloys:		
33	Ajax phosphor bronze.....	Cu, 79; Sn, 10; Pb, 10; P, 0.7	562	77	No. 3S.....	Al, 99; Mn, 1.5	468, 542
34	Ajax plastic bronze.....	Cu, 64; Pb, 30; Sn, 5; Ni, 1	562	78	No. 5S.....	Al, 95; Cu, 2; Zn, 2; Mn, 1.5	
35	Ajax plastic bronze.....	Cu; Sn $\leq 91.9$ ; Pb, $\leq 20$ (U. S. reissue patent 12 880)	561, 562, 567	79	No. 8.....	Al, 95; Cu, 4; Si, $\geq 0.5$ ; Fe, $\geq 0.5$	467, 534, 601
36	Akrit.....	Co, 38; Cr, 30; W, 16; Ni, 10; Mo, 4; C, 2-5	593	80	No. 8S.....	Al, 67; Zn, 33	468, 537
37	Aladar.....	Name used in France for Alpax		81	No. 15S.....	Al; Cu; Zn	
38	Alargan.....	Ag; Al		82	No. 17S§.....	Al, $\leq 92$ ; Cu, 3.5-4.5; Mn, 0.4-1.0; Mg, 0.2-0.75	468, 534, 601, 608
39	Albata (Albatra?).....	Cu, 58; Zn, 23; Ni, 19; Pb, 1.3		83	No. A 17S§.....	Al; Cu, 2.5; Mg, 0.3; Mn, 0	534
40	Albidur-aluminium.....	Al; etc.		84	No. B 17S§.....	Al; Cu, 3.5; Mg, 0.3; Mn, 0	534
41	Albin.....	v. White brass		85	No. 25S.....	Al, 92; Cu, 3.9-5; Mn, 0.5-1.1; Si, 0.5-1	534, 601
42	Alco bronze.....	Cu; Ni		86	No. 51S.....	Al; Si, 0.6-1.2; Mg, 0.45-0.8	536, 601
43	Al-Cu.....	Al; Cu, 7-7.6; Fe, 0.4-0.9; Si; Mn; Zn	467, 534, 601		The above alloys often contain Fe, Mn, Ni, Si, Sn, Zn in subordinate amounts.		
44	Al-Cu, strongest.....	Al; Cu, 3.8			A. S. T. M. casting alloys, Spec. B26-21:		
45	Alcumite.....	Cu; Al, 7.5; Fe, 3.5; Ni; Mn	578, 600	87	A  .....	Al; Cu, 7-8.5; impurities, $\geq 1.7$	467, 534, 537, 600, 601
46	Al-Cu-Mg (casting).....	Al; Cu, 3.4-4; Mg, 0.5; Fe; Mn; Si	468, 534, 601	88	B.....	Al; Cu, 8.5-11; impurities, $\geq 1.7$	
47	Al-Cu-Ni.....	Al; Cu, 2-4; Ni, 1.1-5.3	543	89	C.....	Al; Cu, 9-14; impurities, $\geq 1.7$	
48	Al-Cu-Zn, strong (ingots).....	Al, 83; Zn, 10-13; Cu, 3-5.5; Mn, 0.2-0.4; Fe, Pb; Si; Sn	537				
49	Al-Cu-Zn, strong (cast).....	Al, 80-84; Zn, 11-17; Cu, 3-5; Fe; Mn; Si	537, 601				

\* Resists acid mine water.

† Modified.

\* Many of the recently developed aluminium alloys, although having very varied mechanical properties, have not yet acquired specific names, nor universally used designations. Accordingly, a list of alloys bearing manufacturers' numbers and society specification numbers is included in this table. Some consistent nomenclature is needed, as for instance, there are three alloys labeled "A," two labeled "No. 31," etc.

† Generally known and manufactured in America under this name.

‡ Modified.

§ Duralumin.

|| "No. 12" alloy.



Index No.	Name	Composition	Page
90	D.....	Al; Zn, 12.5-14.5; Cu, 2.5-3.0; impurities, $\geq 1.7$ , Pb, $\geq 0.1$	537-541, 601
91	E.....	Al; Cu, 2-2.5; Mn, 0.75-1.25; impurities, $\geq 1.0$	534, 601
	A. S. T. M. casting alloys, Spec. B26-25T:		
92	A.....	Al, $\leq 96.5$ ; Cu, 1-1.5; Mn, 0.7-2; Fe, $\geq 0.5$ ; Si, $\geq 0.5$ ; Mg; Zn	534
93	B.....	Al, $\leq 92.5$ ; Si, 4.5-6; Fe, $\geq 1.0$ ; Cu, $\geq 0.6$ ; Mn, $\geq 0.2$ ; Zn, $\geq 0.2$ ; Mg	468, 543, 601
94	C*.....	Al, $\leq 90$ ; Cu, 7.0-8.5; Zn, $\geq 0.2$ ; (Fe + Si + Mn + Zn + Sn), $\geq 1.7$	467, 534, 537-541, 601
95	D.....	Al, 88-92; Cu, 6.0-8.0; Zn, $\geq 2.5$ ; Fe, $\geq 1.5$ ; (Si + Mn + Sn), $\geq 10$ This specification will supersede B26-21, above, when adopted.	467, 537-541, 601
	N. P. L. alloys.....	For the more important of these, <i>v.</i> Index Nos. 1, 184, 520, 611, 1490, 1491	
	S. A. E. casting alloys:		
96	No. 30*.....	Same as Index No. 94	
97	No. 31.....	Al, $\leq 81$ ; Zn, 12.5-14.5; Cu, 2.25-3.25; (Si + Fe + Mn + Sn), $\geq 1.7$	537-541, 601
98	No. 32.....	Al, $\leq 85.5$ ; Cu, 11-13.5; Zn, $\geq 0.2$ ; (Si + Fe + Zn + Mn + Sn), $\geq 1.7$	467, 534, 539-541, 601
99	No. 33.....	Same as Index No. 95	
100	No. 34.....	Al, $\leq 87$ ; Cu, 9.25-10.75; Fe, 0.9-1.5; Mg, 0.15-0.35; other elements, $\geq 0.75$	467, 533
101	No. 35.....	Same as Index No. 93	
	For B. E. S. A. Specifications <i>v.</i> p. 386		
102	Aluminum brass.....	Cu, 71-55; Zn, 26-42; Al, 1-6	556
103	Aluminum bronze.....	Cu, 99-89; Al, 1-11 (name also used where other elements are present in smaller amounts than Al)	464, 475, 477, 573-578, 600, 601, 606
104	Aluminum iron bronze.....	Cu, 89-85; Al, 6-9.5; Fe, 3.5-7.5; Mn; Pb; P	578, 579
105	Aluminum magnesium bronze	Cu, 95-90; Al, 5-10; Mg, 0.5	
106	Aluminum manganese bronze.	Cu, 89; Al, 9.6; Mn, 1.2	579, 600
107	Aluminum nickel.....	Ni, 94; Al, 6	
108	Aluminum nickel.....	Ni, 76.4; Al, 23.6	
109	Aluminum nickel bronze.....	Cu, 85; Al, 5-10; Ni, 10-5	581, 600
110	Aluminum silver.....	Al, 95; Cu, 5	534, 601
111	Aluminum silver.....	Cu, 57; Ni, 20; Zn, 20; Al, 3	
	Aluminum solders:		
112	Bates.....	Al, 70; Zn, 30	468, 536
	Bureau of Standards:		
113	SN1.....	Sn, 78; Al, 9; Zn, 8; Cd, 5	
114	SN2.....	Sn, 69; Zn, 26; Al, 2.4; P, 2.4	
115	SN3.....	Sn, 86; Zn, 9; Al, 5; P, 0.25	
116	SN4.....	Sn, 86; Zn, 9; Al, 5	
117	ZN1.....	Zn, 75; Cd, 20; Al, 5	
118	Geophysical Laboratory, Carnegie Institution.....	Zn, 90; Al, 6; Cu, 4	546
119	Roesch.....	Zn, 50; Sn, 49; Sb, 0.7; Cu, 0.2	
120	Seifert.....	Sn, 73; Zn, 21; Pb, 5; P-Sn, 1	
121	So-luminum.....	Sn, 55; Zn, 33; Al, 11; Cu, 1	
122	Sterling.....	Sn, 62; Zn, 15; Al, 11; Pb, 8.3; Cu, 2.5; Sb, 1.2	
123	U. S. patent 1 332 899.....	Sn, 41; Zn, 28; Cu, 3; Mn, 0.6; Al, 0.1	
124	U. S. patent 1 333 666.....	Pb, 92; Cd, 8 There are a host of Al solder patents, many of doubtful value or worthless.	551
125	Wüst.....	Zn, 50; Al, 30; Cu, 20	546
126	Wüst No. 2.....	Zn, 65; Al, 20; Cu, 15	546
127	Aluminum steel.....	Steel deoxidized with Al (Al usually less than 0.2 %).	529
128	Aluminum steel.....	Fe; Al, $\geq 15$ ; C, $\geq 0.9$	529

\* "No. 12" alloy.

Index No.	Name	Composition	Page
129	Aluminum tin bronze.....	Cu, 86; Sn, 10; Al, 2.5; Zn, 2	
130	Aluminum titanium bronze....	Cu, 90-89; Al, 9-10; Fe, 1; Ti, Tr.	577, 601
131	Alzen (Alzene).....	Al, 66.6; Zn, 33.3	468, 536
132	Alzine.....	<i>v.</i> Sibley casting alloy	
133	Amaloy.....	Ni; Cr; W	
134	Amaz metal.....	Cu, 81; Sn, 11; Pb, 7.4; P, 0.3	562
135	Ambrac (30 %).....	Cu, 65; Ni, 30; Zn, 5	480
136	Ambrac.....	Cu, 75; Ni, 20; Zn, 5; Mn, 0.5	480, 601, 606
137	American alloy (so-called in Europe)	Al, 95; Cu, 3; Mg, 1; Mn, 1	468, 534, 601
138	American silver (cast).....	Cu, 58-49; Zn, 21-24; Ni, 15-24; Mn, $< 4$ ; Sn; Fe; Pb; Al	475, 480
139	American silver (cast).....	Cu, 59; Zn, 23; Ni, 11; P-Sn, 5; Pb, 3; Al, 1.5	
140	Amervan.....	Fe, 63.5; V, 35	
141	Ampco (bronze).....	Cu; Al, 7-11; Fe, 1-3	578, 601
142	Anaconda bronze.....	Cu, 90; Sn, 10	559, 601
143	Anatomical alloy (Fusible)....	Bi, 54; Sn, 19; Pb, 17; Hg, 11; Cd	
144	Antifriction alloys ( <i>v.</i> also p. 372).....	Pb, 88-79; Sb, 12-20; Sn, 0-10; Cu; Zn	557
145	Antimonial lead.....	Pb, 100-75; Sb, 0-25	475, 557
146	Apex.....	Fe; Ni	
	Apex bronze.....	<i>v.</i> Sillman bronze	
147	Aphtit.....	Cu, 75-70; Ni, 20-21; Zn, 2.4-5.5; Cd, 1.8-4.5	480, 601
148	Argental.....	Cu, 85; Sn, 10; Co, 5	
149	Argental.....	Al, 75-60; Ag, 15-16; Zn, 7.5-20; Cu, 3.5-5	
150	Argentarium.....	Al; Ag, $< 5$ ; Mg, 0.1-1	
	Argentan:	Nickel silver	
151	Berlin.....	Cu, 56; Zn, 29; Ni, 16	480
152	Berlin castings.....	Cu, 48; Ni, 24; Zn, 24; Fe, 3.6	
153	Chinese.....	Cu, 40; Ni, 32; Zn, 25; Fe, 2.6	
154	French.....	Cu, 50; Zn, 31; Ni, 18	480
155	Resistance.....	Cu, 56; Ni, 26; Zn, 18; Fe, 1	
156	Russian.....	Cu, 64; Ni, 18; Zn, 18; Fe, 0.3; Pb, 0.3	480
157	Russian (cast).....	Cu, 58; Ni, 20; Zn, 19; Fe, 3.2	
158	Sheet.....	Cu, 65-40; Zn, 17-32; Ni, 15-20; Fe	475, 480
159	Argentan solder.....	Zn, 57; Cu, 35; Ni, 8	
	Argent français.....	<i>v.</i> also Mousset's silver	
160	Odessa.....	Cu, 43; Ag, 33; Zn, 16; Ni, 8.5	
161	Roulz.....	Cu, 35-50; Ni, 25-30; Ag, 20-40	
162	Argentin.....	Sn, 85; Sb, 14.5; Cu, 0.5	475
163	Argilite.....	Al, 90; Cu, 6; Si, 2; Bi, 2	
164	Argozoil (Argozie).....	Cu, 54; Zn, 28; Ni, 14; Sn, 2; Pb, 2	
165	Arguzoid.....	Cu, 49-56; Zn, 23-31; Ni, 21-13; Sn, 0-4; Pb, 0-35	
166	Argyroid (Argiroide).....	Nickel silver	
167	Argyrolith.....	Nickel silver	
168	Argyrophan.....	Nickel silver	
169	Arko.....	Cu, 80; Zn, 20	555, 601
170	Armco iron.....	Fe, 99.80-99.94; (P + S + Si + C + Mn), $< 0.14$	470, 600, 602, 606
171	Armstrong (heat resisting stainless steel).....	Fe; Cr, 12; Si, 5; C, 0.5	
172	Arsenic bronze.....	Cu, 80; Sn, 10; Pb, 9.5; As, 0.8	562
173	Ascoloy.....	Fe; Cr, 14	508, 600
174	Ashberry metal (Ashberrium)...	Sn, 78-80; Sb, 14-19; Cu, 0-3; Zn, 0-2.8	557
	A. S. T. M. alloys:		
	The American Society for Testing Materials publishes standard specifications for engineering materials every three years, <i>viz.</i> , 1924, 1927, etc. Tentative standards, not yet adopted, but under consideration are published yearly on Oct. 1.		

Index No.	Name	Composition	Page	Index No.	Name	Composition	Page
	Many of these specifications do not define composition completely, but specify limits for tensile properties, weight per unit area, microstructure, etc.			206	Cu-Sn-Zn-Mn.....	Cu, 86; Sn, 6; Zn, 5; Mn, 2.7	
	Specification numbers preceded by "A" are for ferrous materials and by "B" for non-ferrous materials. The first part of number is the serial number of the specification, and the second part denotes the year of adoption. Numbers followed by "T" denote tentative standards.			207	Cu-Sn-Zn-Pb.....	Cu, 88-75; Sn, 7-14; Zn, 2-9; Pb, 1-9	566
175	Aterite (cast).....	Cu, 67; Zn, 17; Ni, 14; Fe, 1.6; Pb; Mn; Al		208	Cu-Sn-Zn-Pb-P.....	Cu, 82; Sn, 14; Zn, 2; Pb, 1; P, 1	566
176	Aterite (cast).....	Cu, 55-36; Ni, 35-44; Zn, 5-0; Fe, 5-20		209	Cu-Zn-Sn.....	Cu, 77-75; Zn, 14-21; Sn, 4-9	
177	Aterite (rolled).....	Cu, 82-65; Zn, 20-23; Ni, 10-12; Fe, 15-8; Mn; Pb		210	Cu-Zn-Sn-Pb.....	Cu, 67; Zn, 28; Sn, 4.3; Pb, 1.4	
178	Aterite (rolled).....	Cu, 47; Zn, 38; Ni, 11; Mn, 2.2; Fe, 1.9				Max. total impurities	
179	Atba's 2600 ( <i>v. also</i> Rezistal)	Fe; Ni, 22; Cr, 8; Si, 1.75; Cu, 1.0; C, $\geq 0.5$ ; Mn, 0.7			A. S. T. M. Spec. B31-21	Grade:	
180	ATG alloy.....	Ni, 60; Fe, 26; Cr, 10; W, 4		211	1.....	85 10 5 0.27 $\leq 0.7$ 0.50	562
	Automotive steels:			212	2.....	80 10 10 0.50 $\leq 0.7$ 0.75	562
	The Society of Automotive Engineers (U. S. A.) has the following system of numbering steels:			213	3.....	80 10 10 2.00 $\geq 0.05$ 2.50	562
	The first figure indicates the class of steel ( <i>v. below</i> ); the second figure in the case of alloy steels gives the approximate percentage of the predominant alloying element; the last two or three figures indicate the carbon content in hundredths of 1 %.			214	4.....	77 8 15 0.50 $\geq 0.25$ 0.75	562
	The class numbers are as follows:			215	5.....	73 7 20 0.50 $\geq 0.05$ 1.00	562
	1. C steels	5. Cr steels		216	6.....	70 5 25 0.50 0.00 1.00	562
	2. Ni steels	6. Cr-V steels				Fe, $\geq 0.25$ ; Sb, $\geq 0.50$ ; Al, 0 for all; S, $\geq 0.05$ for 1-4 and $\geq 0.25$ for 5 and 6	
	3. Ni-Cr steels	7. W steels			A. S. T. M. Spec. B22-21:		
	4. Mo steels	9. Si-Mn steels		217	A.....	Cu; Sn, $\geq 20$ ;	475, 559,
	Thus SAE2340 is a Ni steel of ca. 3 % Ni and from 0.35-0.45 % C. SAE71360 is a W steel of ca. 13 % W and ca. 0.60C			218	B.....	Cu; Sn, $\geq 17$ ;	560, 601
181	Auer metal (Pyrophoric).....	Fe, 35; Ce, 35; La, 24; Yb, 3; Er, 2	537, 601			P, $\geq 1.0$	476, 559,
182	Auer metal, cheap.....	Fe, 53; Mn, 30; Sb, 10; Miscb metal, 7	476, 557		White metals, lead base:	P, $\geq 1.0$	560, 601
183	Austrian alloy.....	<i>v. Spandau alloy</i>		219	Pb-Sb.....	Pb, 100-80; Sb, 0-20	475, 557
184	Awaruite (natural).....	Ni, 75; Fe, 25		220	Pb-Sb-Sn.....	Pb, 86-60; Sb, 10-20; Sn, 1-20	557
185	"B" alloy.....	Al; Zn, 25; Cu, 3		221	Pb-Sb-Sn-Cu.....	Pb, 78-68; Sb, 17-21; Sn, 7.3-9.6; Cu, 0.4-2	557
186	Babbitt (genuine).....	Sn, 89; Sb, 7.3; Cu, 3.7		222	Pb-Sn-Sb.....	Pb, 80-40; Sn, 10-45; Sb, 10-20	557
187	Babbitt metals.....	Pb and Sn base bearing alloys		223	Pb-Sn-Sb-Cu.....	Pb, 83-46; Sn, 7.7-40; Sb, 7.7-17; Cu, 0.5-8	557
188	Bahn Metall.....	Pb; Ca, 0.7; Na, 0.6; Bi, 0.04	556			(For lead hardened with other elements, <i>v. Index</i> Nos. 186, 390, 602, 867, 1433)	
189	Bario (sheet).....	Ni, 90; Cr, 4.3; W, 1.2; Si, 0.3; Co; Cu; Fe			A. S. T. M. Spec. B23-18T*	Grade:	Max.
190	Bario-metal (hard).....	Cr, 30; Co, 30; W, 25; Mn, 10; Ti, 5		224	6.....	Pb 63.5 15 20 1.5 0.15	557
191	Bario-metal (soft).....	Co, 60; Cr, 20; W, 20		225	7.....	75 15 10 0.5† 0.20	
192	Baros.....	Ni, 90; Cr, 10	467	226	8.....	80 15 5 0.5† 0.20	557
193	Basic bessemer pig.....	Fe; C, 3.5-4; P, 2-3; Si, $\geq 1$ ; Mn, $\geq 0.5$ ; S, $\geq 0.05$	476	227	9.....	85 10 5 0.5† 0.20	
194	Basic low phosphorous pig.....	Fe; C, 3.5-4; Mn, 1-2.5; Si, $\geq 1.25$ ; P, 0.1-1; S, $\geq 0.05$	476	228	10.....	83 15 2 0.5† 0.20	
195	Bath metal.....	Cu, 83; Zn, 17	475, 555	229	11.....	85 15 0.5† 0.25	557
196	Bath metal.....	Cu, 55; Zn, 45	470, 555	230	12.....	90 10 0.5† 0.25	557
197	Battery copper.....	Cu, 94; Zn, 6	469, 555	231	S. A. E. Spec. 13*	Pb, $\geq 86$ ; Sb, 9.25-10.75; Sn, 4.5-5.5; Cu, $\geq 0.5$ ; As, $\geq 0.2$	557
198	Battery plates.....	Pb, 94; Sb, 6	557	232	S. A. E. Spec. 14*	Pb, $\geq 76$ ; Sb, 14-16; Sn, 9.25-10.75; Cu, $\geq 0.5$ ; As, $\geq 0.2$	557
199	Battery plates.....	Zn, 63; Sn, 21; Pb, 12; Cu, 3.2			War Service Assn. of Mfrs. of Solder and Bearing Metals*		
200	Baudrin's (Baudoin's?) alloy.....	Cu, 72; Ni, 17; Zn, 7.1; Sn, 2.5; Co, 1.8; Al, 0-0.5		233	Grade B.....	Pb, 46; Sn, 45; Sb, 7.5; Cu, 1.5†	
201	B. E. 4 alloy (Bureau of Engineering, U. S. N.)	Al; Cu, 4; Mg, 0.25; Fe, $\geq 0.5$ ; Si, $\geq 0.1$	467, 534, 601	234	Grade C.....	Pb, 60; Sn, 30.5; Sb, 8.5; Cu, 1†	
202	Bearing alloys:	For a list of index numbers of bearing alloys, <i>v. p. 391</i> . The ranges of compositions of the different types are given here, and also some A. S. T. M. and S. A. E. bearing alloy specifications.			White metals, tin base:		
203	Bronzes:			235	Sn-Pb-Sb-Cu.....	Sn, 74-42; Pb, 12-40; Sb, 9.5-16; Cu, 1-4.7	557
204	Cu-Pb-(S).....	Cu, 70-30; Pb, 30-70; S, $\geq 1$	561, 562	236	Sn-Sb-Cu.....	Sn, 91-72; Sb, 6-26; Cu, 2-9	476, 557
205	Cu-Pb-Sn-(S).....	Cu, 84-50; Pb, 8-40; Sn, 6-10; S	561, 562	237	Sn-Sb-Pb.....	Sn, 75; Sb, 15; Pb, 10	
206	Cu-Sn-Pb-Sb.....	Cu, 80; Sn, 16; Pb, 2; Sb, 2		238	Sn-Sb-Pb-Cu.....	Sn, 75-70; Sb, 12-15; Pb, 9-11; Cu, 3-11; Fe; Zn	476, 557
207	Cu-Sn.....	Cu; Sn, $\geq 20$	475, 559	239	Sn-Zn-Cu.....	Sn, 72; Zn, 27; Cu, 1.3	
208	Cu-Sn-P.....	Cu; Sn, $\geq 20$ ; P, $\geq 1$	560, 601		A. S. T. M. Spec. B23-18T	Grade*:	Max.
209	Cu-Sn-Zn.....	Cu, 86-83; Sn, 8.8-15; Zn, 1-7.5	476, 563	240	1.....	Sn 91 4.5 $\geq 0.35$ 4.5 0.10	557
				241	2.....	89 7.5 $\geq 0.35$ 3.5 0.10	557
				242	3.....	83.3 8.3 $\geq 0.35$ 8.3 0.10	557
				243	4.....	75 12 10 3 0.15	557
				244	5.....	65 15 18 2 0.15	557

\* Zn and Al, 0.

† Maximum.

‡ Fe,  $\geq 0.08$ ; As,  $\geq 0.15$ .



Index No.	Name	Composition	Page
245	S. A. E. Spec. 10*†	Sn, <90; Cu, 4-5; Sb, 4-5; Pb, >0.35	557
246	S. A. E. Spec. 11*†	Sn, <86; Cu, 5-6.5; Sb, 6-7.5; Pb, >0.35	
247	S. A. E. Spec. 12*†	Sn, <59.5; Pb, >26; Sb, 9.5-11.5; Cu, 2.25-3.75	
248	War Service Assn. of Mfrs. of Solder and Bearing Metals Grade A*	Sn, 61.5; Pb, 25; Sb, 10.5; Cu, 3; As, >0.15	557
249	White metals, zinc base:		
250	Zn-Cu-Sn-Sb	Zn, 88; Cu, 8; Sn, 2; Sb, 2	
251	Zn-Sn-Al-Pb-Cu	Zn, 55; Sn, 23; Al, 20; Pb, 1.3; Cu, 0.6	
252	Zn-Sn-Cu	Zn, 85-67; Sn, 10-30; Cu, 4.2-7.4	
253	Becket alloy	Fe; Cr, 25-30; Si, 3; C, 1.5-3	
254	Bell brass	Cu, 64; Zn, 35; Sn, 0.8	556
255	Bell metals:		
256	Herbohn	Al, 83; Mn, 10; Cd, 7	
257	Japanese kara kane	Cu, 75-80; Sn, 25-20	559, 561
258	Musical	Cu, 71-60; Sn, 26-35; Zn, 2.7-5.0	
259	Bemal	Cu, 72-61; Sn, 14-25; Pb, 0-14; Zn, 0-9.4; Fe, 0-3.0	
260	Benedict metal	Cu, 84; Sn, 16	475, 559
261	Benedict nickel	Cu, 70; Zn, 29; P, 0.45; Fe, 0.15	469, 555
262	Benedict plate	Cu, 86-84; Ni, 14-16; C, <0.04	480
263	Berlin alloy	Cu, 79; Ni, 20; Fe, 0.36	480, 601
264	Bernda metal	Cu, 57; Zn, 28; Ni, 15	480
265	Bersch bearing alloy	Cu, 63-52; Zn, 31-26; Ni, 6-22	480, 601
266	Berthier's alloy	A high tensile brass	
267	Berthier's alloy	Al, 93; Ni, 7	543
268	B. E. S. A. alloys	Cu, 68; Ni, 32	601
269	Best bronze	Cu, 72; Zn, 25; Pb, 2; Sn, 1.2	
270	Biddery	British Engineering Standards Assn. Spec. v. p. 386	
271	Bierman tungsten bronze	Cu, 90; Zn, 10	469, 555
272	Bilgen-bronze	Zn, 90-84; Cu, 6.3-11; Pb, 2.5-3; Sn, 0.8-1.4	
273	Birmingham platinum	Cu, 95; Sn, 3.4; W, 1.6	
274	Bismuth brass	Cu, 97; Sn, 1.9; Fe, 0.5; Pb, 0.2	559
275	Bismuth bronze	Zn, 79-53; Cu, 20-47; Fe, 0.3	465, 546
276	Bismuth bronze	Cu, 52; Ni, 30; Zn, 12; Pb, 5; Bi, 1	
277	Bismuth bronze	Cu, 47; Ni, 31; Zn, 21; Sn, 1; Bi, 1	
278	Bismuth bronze	Cu, 45; Ni, 33; Zn, 22; Sn, 16; Bi, 1	
279	Bismuth bronze	Cu, 53; Zn, 20; Sn, 15; Ni, 10; Bi, 1; Al, 0.1	
280	Black heart	v. Index No. 836	
281	Blanko-blech	Cu, 80; Ni, 20	480, 601
282	Blatt gold	Cu, 77; Zn, 23	555, 601
283	Blatt-silver	Sn, 91; Zn, 8.3; Pb, 0.4; Fe, 0.2	
284	Bloch's alloy	Co, 54; Ni, 45; Si, 0.9; C, 0.3; Mn; P; S	
285	Blue gold	Au, 75; Fe, 25	
286	Bobierre metal	Cu, 66-58; Zn, 34-42	555, 601
287	Böhler magnet steel	Fe; W, 6.3; C, 0.7; Mn; P; S; Si	472
288	Böhler rapid steel	Fe; W, 14; Cr, 3.9; C, 0.7	472
289	Böhler super rapid steel	Fe; W, 15; Cr, 3.7; C, 0.8; V, 0.2; Mo, 0.2; Mn; P; S; Si	472
290	Borcher's non-corrosive alloys	Cr, 65; Fe, 35	
291	Boronized copper	Co, 35; Ni, 35; Cr, 30	
		Co, 34; Ni, 34; Cr, 30; Ag, 2	
		Co, 35; Ni, 35; Cr, 30; Mo, 0.5-5	
		Fe, 60; Cr, 36; Mo, 4	
		Cu deoxidized with B, no excess present	558

\* Zn and Al, 0; Fe, &gt;0.08.

† As, &gt;0.1; Bi, &gt;0.08.

Index No.	Name	Composition	Page
292	Boron steel	Fe; B, 0.06-0.4; C, 0.45-0.16; Al; Si; Mn	530
293	Bourbonnes	Sn, 51; Al, 49; Fe, 0.3; Cu, 0.3	
	Brass	For list of brasses, v. p. 389	
	Brass ingots, A. S. T. M. Spec. B30-22*		
	No.	Cu Zn Sn Pb Fe	Max.
294	1	87 3 8 >2	0.25
295	2	85 5 5	0.35
296	3	83 7 4	0.35
297	4	77 10 3	0.40
298	5	76 16 2	0.40
299	6	65 33 >1	0.50
300	7	60 37 >1.5	1.00
	For B. E. S. A. Specifications	v. p. 386	
301	Brazing brass	Cu, 80-75; Zn, 20-25; Pb; Fe	460, 555
302	Bridge bronze A	Cu, 80; Sn, 20; P, 0.1	475, 559
303	Bridge bronze B	Cu, 85; Sn, 15; P, 0-1	475, 560
304	Bridge bronze C	Cu, 80; Sn, 10; Pb, 10; P, 0.7-1	562
305	Bridge bronze D	Cu, 88; Sn, 10; Zn, 2; P, 0.3	476, 566
306	Bright cap gilding	Cu, 90; Zn, 9.9; Pb, 0.4	469, 555
307	Brightray	Similar to Chromel A	
308	Bristol brass	Cu, 76-61; Zn, 24-39	555, 601
	Brittania metal:		
309	Cast	Zn, 48; Sn, 48; Cu, 3; Pb, 1; Sb, 1	476
310	Cast	Sn, 91-85; Sb, 9-11; Zn, 0-3; Cu, 0.2-1	476, 557
311	English	Sn, 90-85; Sb, 5-10; Cu, 1-3; Zn, 0-3; Bi, 0-2	557
312	German	Sn, 94-70; Sb, 3.7-15; Cu, 1.8-5; Pb, 0-9; Zn, 0-5	557
313	Plate (Ludenscheidt)	Sn, 72; Sb, 24; Cu, 3.9	
314	Plate	Sn, 91-90; Sb, 7-8; Cu, 1.4	557
315	Spoons	Sn, 88-85; Sb, 5.6-15; Bi, 1-5; Cu, 0.1-3.7; Zn, 0-1.5	
316	Brix	Ni, 75-60; Cr, 15-20; Cu, 5; Si, 4; Ti, 3; Al, 2; W, 1-4; B, 1; Mn	
317	Brolunick	Cu; Al; Ni	
	Bronze	For list of bronzes, v. p. 389	
318	Bronze powder	Cu, 84; Zn, 16	
319	Bronze wire	Cu, 99; Sn, 1.2; P, 0.05	565
320	B. T. G. steel	Ni, 60; Fe, 25; Cr, 12; Mn, 2; C, 0.5	467, 480
321	Burr metal	Cu, 90; Zn, 10	469, 555
322	Butt brass	Cu, 64; Zn, 36; Pb, 1	555, 602
323	Button alloy	Cu, 60-50; Zn, 30-45; Sn, 0-10	555, 556, 601
324	Button brass	Cu, 90; Zn, 10; Sn, 0.5	465, 555
	Cadmium silver	v. Index No. 1330	
325	Caedit	Similar to Stellite	
326	Calido, Elalco	Ni, 60; Fe, 24; Cr, 16	467
327	Calido, Elalco	Ni, 64; Fe, 25; Cr, 8; Mn, 3	
328	Calite A	Fe; Ni, 35; Cr, 15; C, 0.8	512
329	Calite B	Fe; Cr, 18; Ni, 6; C, 1.5	512
330	Calorite	Ni, 65; Fe, 15-23; Cr, 12; Mn, 0-8	
331	Camelia metal	Cu, 70; Pb, 15; Zn, 10; Sn, 4.2; Fe, 0.5	561
332	Can-metall (German)	Pb, 95; Ca, 1.75; Cu, 1.35; Sr, 1; Ba, 1	556
333	Cap gilding	Cu, 90; Zn, 10	469, 555
334	Capsule metal	Pb, 92; Sn, 8	467, 557
335	Carbon bronze	Cu, 75; Pb, 15; Sn, 9.7	561
	Carbon steels	For list, v. p. 390	
336	Carbondale silver	Cu, 66; Ni, 18; Zn, 16	480
337	Carburite (recarburizer)	C, 47-48; Fe, 28; S, 0.3; P, 0.2; binder	
338	Careco	A white bearing alloy	
339	Cartridge brass	Cu, 67-70; Zn, 33-30; Pb; Fe	469, 555
340	Cartridge gilding	Cu, 93; Zn, 7	469, 555

\* S, &gt;0.05; Al, 0 except 0.3 % allowable in 6 and 7; Sb, &gt;0.25 in 1-3, and 5. &gt;0.35 in 4, and &gt;0.20 in 6 and 7; P, &gt;0.05 in 1-5 and &gt;0.02 in 6 and 7. v. also p. 372.

Index No.	Name	Composition	Page	Index No.	Name	Composition	Page
341	Case-hardening steel.....	Fe; C, $\geq 0.20$ ; Mn; Si; P; S (or low carbon alloy steel)	470, 488, 600, 606	386	Clichier metal.....	Pb, 40-50; Sn, 33-36; Cd, 21-14	
	Cast iron.....	For list, v. p. 390		387	Clichier metal.....	Sn, 80; Bi, 15; Pb, 5	
	Cast steel.....	v. Index No. 1335. (The name is also applied to crucible steel)		388	Clichier metal.....	Sn, 48; Pb, 33; Sb, 11; Bi, 9	
342	Ccco.....	Cu, 62.5; Pb, 32; Sn, 4.6; Ni, 0.9; Fe, $< 0.03$	562	389	Climax.....	Fe, 73; Ni, 24; Mn, 2.6	482
343	Celsit.....	Similar to Stellite		390	C. M. A. bearing metal.....	Pb; alkaline earth metals	556
344	Cerium steel.....	Fe; Ce, 0.2-0.6; C, 0.4; Mn, 0.7; Si, 0.4-0.8	531, 605	391	Cobaltcrome.....	Fe, 80; Cr, 14; Co, 3.7; C, 1.5; Mo, 0.8; Si, 0.8	
345	Chain bronze.....	Cu, 95; Sn, 4.9; P, 0.1	560, 601	392	Cobaltcrome.....	Fe, 70-60; Cr, 30-25; Co, 5-10	
346	Chain iron (A. S. T. M. Spec. A53-24)	Grade AA: Mn, $\geq 0.10$ ; Grade A: Mn, $\geq 0.2$ (strength specified)		393	Cobalt steel.....	Fe; Co, 0.5-17; C, 0.15-0.9; Mn; P; S	
347	Chain steel (A. S. T. M. Spec. 156-24)	Grade BBB: P, $\geq 0.04$ ; S, $\geq 0.04$ (strength specified)			Coinage alloys.....	v. Index Nos. 975, 1249, 1250, 1326, 1327, 1329, 1330	
348	Chamet bronze.....	Cu, 62; Zn, 38	555, 601	394	Coinage bronze.....	Cu, 95; Sn, 4; Zn, 1	561
349	Charcoal pig iron (Lake Superior)	Fe; C, 3-4; Si, 0-2.6; P, 0.15-0.25; Mn, 0.3-0.7; S, $\geq 0.02$		395	Collet brass.....	Cu, 61; Zn, 37; Pb, 2.5	602
350	Charpy phosphor bronze.....	Cu, 85; Sn, 12-13; P, 0.4-0.5	560	396	Colorado metal.....	Cu, 57; Ni, 25; Zn, 18	475, 480
351	Checo (dental).....	Ag, 89; Sn, 10; Pt, 1		397	Comet.....	Fe, 70; Ni, 30; Cr, 2.2; Mn, 0.8; Cu, 0.4	
352	Chemical lead.....	Pb; Cu, 0.04-0.08; Ag, 0.005-0.015; Bi, $\geq 0.005$	461, 475, 556		Commercial bar steel.....	v. Index Nos. 1336-1341	
353	Chilled cast iron wheels (A. S. T. M. Spec. A46-24) (Key No. 117, p. 497)	Total C, $\leq 3.25$ ; combined C, $\geq 0.85$ ; Si, 0.45-0.75; Mn, 0.5-0.75; P, $\geq 0.4$ ; S, $\geq 0.15$	470, 476, 497	398	Commercial brass, B-r.....	Cu, 63; Zn, 37 (rolled)	555, 601
354	China silver.....	Nickel silver		399	Commercial brass, B-c.....	Cu, 62; Zn, 30; Sn, 6; Pb, 2 (cast)	
355	Chinese bronze.....	Cu, 83-72; Pb, 10-20; Zn, 0.7-14; Sn, 1-13; Fe (v. also Index No. 912)	561	400	Commercial brass wire.....	Cu, 64; Zn, 36; Pb, 0.2; Fe	469, 601
356	Chinese silver.....	Cu, 58; Zn, 17.5; Ni, 11.5; Co, 11; Ag, 2		401	Commercial bronze.....	Cu, 90; Zn, 10; Pb; Fe	469, 555
357	Chinese speculum.....	Cu, 81; Sn, 11; Sb, 8.5		402	Commercial bronze rod.....	Cu, 86; Zn, 12.75; Pb, 0.75; Sn, 0.5	469, 555
358	Chinese speculum (Elsner's)...	Cu, 81; Pb, 9; Sb, 8		403	Common high brass.....	Cu, 65; Zn, 35	555, 601
359	Christofle metal.....	Silver-plated German silver (Ag, 2)		404	Complex English metal.....	Sn, 87; Sb, 6; Ni, 2; Cu, 2; W, 1.5; Zn, 1; Bi, 0.5	
360	Chromal steel.....	Fe; Cr, 0.8; Mn, 0.8; Mo, 0.8; C, 0.3	472, 605		Condenser foil.....	v. Accumulator metal	
361	Chromaluminium.....	Al; Cr		405	Constantan.....	Cu, 60-45; Ni, 40-55; Mn, 0-1.4; C, 0.1; Fe	464, 480, 601, 606
362	Chromax (Kromax?).....	Ni, 75; Cr, 25		406	Cook's alloy.....	Sb, 57-69; Zn, 32-43	
363	Chromax bronze.....	Cu, 67; Ni, 15; Zn, 12; Al, 3; Cr, 3		407	Cooperite.....	Ni, 80; W, 14; Zr, 6	
364	Chrome iron.....	Similar to Duraloy		408	Cooper's gold.....	Cu, 81-67; Pt, 19-30; Zn, 0-4	
365	Chromel No. 502.....	Fe, 55; Ni, 25; Cr, 20		409	Cooper's mirror.....	Cu, 58; Sn, 28; Pt, 9.5; Zn, 3.5; As, 1.5	
366	Chromel A.....	Ni, 80; Cr, 20	480, 608	410	Cooper's pen metal.....	Cu, 50; Au, 25; Ag, 25	586
367	Chromel B.....	Ni, 85; Cr, 15	467, 480	411	Cooper's pen metal.....	Pt, 50; Ag, 38; Cu, 12	480, 601
368	Chromel C.....	Ni, 65; Fe, 24; Cr, 11	467, 480	412	Copel.....	Cu, 55; Ni, 45	
369	Chromel D.....	Fe, 66; Ni, 26; Cr, 8			Copper (commercial):		
370	Chromel P.....	Ni, 90; Cr, 10	467	413	Arsenical lake.....	Cu, 99.4; As, 0.3; O, 0.2	460, 552
371	Chrome-molybdenum steel....	Fe; Cr, 0.5-1; Mo, 0.1-1.0; C, 0.1-0.5; Mn; Si; P; S	472, 604, 605	414	Best select.....	Cu, 99.5	553, 601
372	Chrome-nickel steel (ordinary range)	Fe; Ni, 1.25-3.5; Cr, 0.6-1.5; C, 0.2-0.6; Mn, $\geq 0.7$ ; P, $\geq 0.04$ ; S, $\geq 0.05$ ; Si, low	472, 510, 518, 600, 604-608	415	Electrolytic.....	Cu, 99.90-99.993	552, 601
373	Chrome-nickel steel armor plate (heavy) (Key No. 268, p. 512)	Fe; Ni, 4; Cr, 2; C, 0.33; Mn, 0.32; Si, 0.06; S, 0.03; P, 0.14 (v. also Projectile steel)	472, 512	416	Lake.....	Cu, 99.9	552, 601
	Chrome-tungsten steel.....	v. High-speed steel		417	Oxygenated.....	Cu; O, 0.04-0.2	554, 601
374	Chrome-uranium steel.....	Fe; Cr, 0.8; U, 0.17-0.3; C, 0.3-0.4; Mn; Si	478		Copper-manganese.....	v. Cupromanganese	
375	Chrome-vanadium steel.....	Fe; Cr, 0.7-1.4; C, 0.15-0.6; V, 0.12-0.3; Mn, 0.3-0.9; Si, 0.2; P, $\geq 0.01$ ; S, $\geq 0.04$	472, 509, 517, 600, 604, 605		Copper-nickel.....	v. Cupronickel	
376	Chromium steel (commercial pearlitic)	Fe; Cr, 2-5; C, 0.2-0.8; Mn; Si; P; S (v. also p. 390)	507-509, 517, 605	418	Copper steel.....	Fe; Cu, $\geq 4$ ; C, $\geq 1.1$ ; Mn; Si; P; S	509
377	Chrysotite (dental).....	Cu, 63; Zn, 37; Pb, 0.24	555, 603	419	Cornish bronze.....	Cu, 78; Sn, 9.6; P, 0.8	560, 601
378	Chrysokalk.....	Cu, 59; Zn, 40; Pb, 1	602	420	Corronil.....	Ni, 70; Cu, 26; Mn, 4	480, 604
379	Chrysokalk.....	Cu, 91; Zn, 7.9; Pb, 1.6	469	421	Corrosion-resisting alloy.....	Pb, 91; Cu, 4.5; Ni, 4.5 (for list v. p. 391)	
380	Chrysorin.....	Cu, 72-63; Zn, 28-37	555, 601	422	Corrosion-resistant steel (Carpenter).....	Fe; Cr, 9.5; C, 0.45	470, 508
381	Cimet.....	Fe; Cr, 25		423	Corrosiron.....	Fe, 85.5; Si, 13.5	473
382	Chrome-silicon steel.....	v. Index No. 1235		424	Corsonite* A.....	Cu; Ni; Si	
383	Clark's patent.....	Cu, 75; Ni, 14; Zn, 7.2; Sn, 1.9; Co, 1.9		425	Corsonite B.....	Cu; Co; Si	
384	Clebrum.....	Fe; Cr, 13; Mo, 3.6; C, 2.6; Ni, 2; Si, 1.5; Mn, 0.8		426	Corsonite C.....	Cu; Fe; Si	
385	Clebrum.....	Fe; Cr, 19; Ni, 4.6; Mn, 2.8; C, 2; Cu, 2		427	Corsonite D.....	Cu; Cr; Si	
				428	Corsonite E.....	Cu; Cr	
				429	Corsonite F.....	Cu; Co	
				430	Cowles high Mn brass.....	Cu, 80-67; Mn, 15-18; Zn, 5-13; Al, 0-1; Si	
				431	Craig gold.....	Cu, 80; Ni, 10; Zn, 10	
				432	Crank case alloy.....	Al, 91-90; Cu, 7-8; Fe, 1-1.8; Zn, 0-1.8	467, 534, 601
				433	Crescent steel.....	Fe; W, 6.7; Mn, 2.7; C, 2.1; Si, 0.1	
				434	Crodon.....	Cr alloy plating	
				435	Cronite.....	Ni, 60; Cr, 40	
				436	Crotorite.....	Cu, 70; Mn, 30; Fe, 2	

\* Name given by Mr. Corson to these alloys which were developed at the Union Carbide and Carbon Research Laboratories, Inc. v. *Metal Industry* (N. Y.) Sept., 1926.



Index No.	Name	Composition	Page	Index No.	Name	Composition	Page
437	Crucible steel (also called cast steel)	Fe; C, 0.65-1.55; Mn; Si; P; S. (Graded according to "temper," one temper unit generally meaning 0.1 % C. Designation varies with manufacturer.)	470, 477, 492-497, 516-518, 600, 602, 603, 605-608	493	Dowmetal D.....	Mg, 88; Al, 8.3; Cu, 2.0; Cd, 1.0; Zn, 0.5; Mn, 0.2	544
438	Cufenium.....	Cu, 72; Ni, 22; Fe, 6		494	Dowmetal E.....	Mg, 94; Al, 5.8; Mn, 0.2	544, 604
439	Cuivre poli.....	Cu, 70; Zn, 30	555, 601	495	Dowmetal R.....	Mg, 90; Al, 8; Cu, 1; Cd, 1	544
440	Cuniloy.....	Ni, 65; Mn, 35; Cu, 25; Pb, 1		496	Dowmetal T.....	Mg, 92; Cu, 3.8; Cd, 2; Mn, 0.2	544
441	Cupola malleable iron.....	Fe; C, 3.0; combined C, Tr.; Si, 0.9; Mn, 0.8; P, 0.2; S, 0.15	476, 497, 525, 526	497	Drawing brass.....	Cu, 70-67; Zn, 33-30 ( <i>v. also</i> Index Nos. 1409, 1486)	469, 555, 601
	Cupro-aluminium.....	<i>v.</i> Aluminum bronze		498	Dudley's antifriction alloy.....	Sn, 98; Cu, 1.6; Pb, 0.3	
442	Cupromagnesium.....	Cu, 90; Mg, 10		499	Dudley's bearing metals.....	<i>v.</i> Index Nos. 553, 556	
443	Cupromanganese.....	Cu, 90; Mn, 10	554	500	Dudley's phosphor bronze.....	Cu, 80; Sn, 10; Pb, 9.6; P, 0.8	562
444	Cupromanganese tubes.....	Cu, 96; Mn, 4	554, 600	501	Duke's metal.....	Ni, 40; Cu, 30; Fe, 30	
	Cupronickel:			502	Duke's metal.....	Fe, 81; Cr, 12; C, 1.5; Co, 4; Si, 0.6; W, 0.4; Mn, 0.2	
445	Bullet jackets.....	Cu, 85; Ni, 15; C, <0.04	480	503	Dumet.....	Fe, 54; Ni, 46; (Cu, plated)	467, 481
446	Commercial.....	Cu, 98-60; Ni, 2-40	480, 601	504	Dunnlevic and Jones antifriction.....	Pb, 60; Sb, 20; Zn, 20	
447	Driving bands.....	Cu, 97.5-95; Ni, 2.5-5	480	505	Dunnlevic and Jones antifriction.....	Zn, 85-80; Sb, 10; Sn, 5-8	476
448	Ingots.....	Cu, 50; Ni, 50	480	506	Dunnlevic and Jones antifriction.....	Zn, 52; Sn, 46; Cu, 1.6; Sb, 0.4	
449	Locomotive tubes.....	Cu, 97; Ni, 3	480	507	Duraloy (Key No. 191, p. 508)	Fe; Cr, 25-30; Mn, 0.6; Si, 0.5; P (sometimes only 20 % Cr)	508
450	No. 300 alloy.....	Cu, 89; Ni, 11	480	508	Duralumin.....	Al; Cu, 3.5-5.5; Mg, 0.5-0.8; Mn, 0.5-0.8; Fe; Si	468, 534, 601, 608
451	Sheet.....	Cu, 81-79; Ni, 19-21	480, 601	509	Duralumin (imitation).....	Al, 79; Mg, 11; Cu, 10; P, 0.05	
452	Cuprosilicon.....	Cu; Si, > 55	554, 594	510	Duralumin, special ("Y" alloy)	Al, 92.5; Cu, 4; Ni, 2; Mg, 1.5	534, 601, 608
453	Cupror.....	Cu, 94; Al, 5.8	574, 601	511	Durana metal.....	Cu, 65; Zn, 30; Pb, 2; Al, 1.5; Fe, 1.5	556
454	Cyclops No. 17 metal.....	Fe; Ni, 20; Cr, 7.5; Si, 1.00; Mn, 0.75; C, 0.45	604	512	Durana metal.....	Cu, 59; Zn, 40; Sn, 1; Pb, 0.4; Fe, 0.3	470, 556
455	Cymbal metal.....	Cu, 78; Zn, 22	555, 601	513	Durand's alloy.....	Al, 67; Zn, 33	468, 536
456	Cyprus bronze.....	Cu, 65; Pb, 30; Sn, 5	562	514	Durex.....	Cu, 83; Sn, 10; Graphite, 4.4-4.7	
457	Daimler bearing.....	Cu, 76; Zn, 20; Sn, 3; Pb, 1		515	Duriron.....	Fe; Si, 14-15; Mn, 2-2.5; C, 0.8-1.3; S, 0.05-0.2; P, 0.05-1	473
458	Damar.....	Cu, 76; Pb, 13; Sn, 11	562	516	Duriron.....	Fe; Si, 14-15; Mn, 0.3-0.4; C, 0.2-0.6; P, 0.2; S, 0.05	473
459	Damascus bronze.....	Cu, 77; Pb, 13; Sn, 10	562	517	Dutch metal (Dutch leaf, Dutch gold).....	Cu, 76; Zn, 24	555, 601
460	Dandelion metal.....	Pb, 72; Sb, 18; Sn, 10		518	Dynamo sheets.....	Fe; Si, 3-4; C, <0.1; Mn, <0.3; (P + S), <0.03	472, 524
461	D'Arcet.....	Bi, 50; Pb, 25; Sn, 25		519	Dysoid.....	Cu, 62; Pb, 18; Sn, 10; Zn, 10	
462	Dark red gold.....	Au, 50; Cu, 50	586	520	"E" alloy (rolling).....	Al; Zn, 20; Cu, 2.5-3; Si, 0.2-1; Mg, 0.5; Mn, 0.5; Fe	538, 601, 608
463	Davis metal.....	Cu, 67; Ni, 29; Fe, 2; Mn, 1.5; (C + Si), 0.5		521	E. B. D. bearing.....	Cu, 90-88; Sn, 10; P-Sn, 5; Zn, 2	
464	Degussa alloy.....	Cu, 66; Zn, 34; Fe	556, 601		Edelmessing.....	High tensile brass	
465	Delatot's metal.....	Cu, 80; Zn, 18; Mn, 2			Edelstahl.....	Alloy steel	
466	Delhi hard iron.....	Fe; Cr, 17; Si, 1.5; C, 1.2		522	Edwards speculum.....	Cu, 70-63; Sn, 25-32; As, 2.4-1.6; Zn, 2.6-0	
467	Delhi tough iron.....	Fe; Cr, 17; Si, 1.25; Mn, 0.3; C, 0.07		523	Ebrhardt's metal.....	Zn, 89; Cu, 4; Sn, 4; Pb, 3	
468	Delta metal.....	Cu, 56-54; Zn, 40-44; Fe, 0.9-1.3; Mn, 0.8-1.4; Pb, 0.4-1.8; P	464, 556, 602	524	Ebrhardt's type metal.....	Zn, 89; Sn, 6; Cu, 3; Pb, 2	
469	Demo bronze.....	Cu, 61; Pb, 33; Sn, 4-6; Ni, 2-1	562	525	Einheitsmetall.....	Pb, 79; Sb, 14; Sn, 5.3; Cu, 1.5	557
470	Dewrance metal.....	Sb, 45; Sn, 33; Cu, 22		526	Eisenbronze.....	<i>v.</i> Iron bronze	
471	Diamond bronze.....	Cu, 88; Al, 10; Si, 2		527	Eislers (bronze).....	Cu, 94; Sn, 5.9	559, 601
472	Diapbragm brass.....	Cu, 95; Sn, 3; Zn, 2		528	Elalco alloys.....	<i>v.</i> Index Nos. 326, 717, 830	
	Die-casting alloys:			529	Electrical brass, B. E.....	Cu, 84; Zn, 13; Sn, 3	
473	.....	Al, 92-82; Cu, 8-18; Fe, 0-3; Mg; Mn; Si; Zn	534, 601	528	Electrometall.....	Al; Mg; <i>v.</i> Electron	
474	High grade bearings.....	Sn, 91-84; Sb, 2-9; Cu, 4.5-8	476, 557		Electron.....	Generic name of some Mg base alloys containing up to 12 % Al, as:	
475	Light duty bearings.....	Pb, 90-80; Sb, 10-17; Sn, 10-0; Cu, 0-1	475, 557	530	Electron.....	Mg, 90; Al, 3-7; Zn, 2-5; Mn, 0.5	545
476	Light duty bearings.....	Sn, 80; Pb, 10; Sb, 10		531	Electroplate.....	Cu, 50-70; Ni, 10-20; Zn, 5-30	545, 604
477		Sn, 61.5; Pb, 25; Sb, 10.5; Cu, 3		532	Electrotype (standard).....	Pb, 93; Sb, 4; Sn, 3	475, 480, 601, 606
478	Soft work.....	Zn, 74; Sn, 15; Al, 6; Cu, 5		533	Electrum.....	Cu, 52; Ni, 26; Zn, 23	476, 480
479	Standard.....	Zn, 85; Sn, 8; Cu, 4; Al, 3		534	Electrum.....	Au, 85-55; Ag, 15-45	586
480	Hard.....	Zn, 82.75; Al, 13.75; Cu, 3	546	535	Elephant bronze.....	Cu, 95.5; Sn, 3.9; P, 0.3; Fe, 0.16	464, 560, 600
481	Hard.....	Zn, 46; Sn, 31; Cu, 20; Sb, 3					
482	Strong, hard.....	Zn, 86.5; Cu, 10.75; Al, 2.75	546				
483		Zn, 90-83; Cu, 5-11; Al, 2-5; Sn, 1-5 ( <i>v. also</i> Index No. 955 and white metals)					
484	Dienett's German silver.....	Cu, 51; Zn, 32; Pb, 9.5; Ni, 6.4; Sn, 1.6					
485	Diesel bearings.....	Sn, 80; Sb, 15; Cu, 5					
486	Dilver.....	<i>v.</i> Platinite					
487	Dipping brass.....	Cu, 67; Zn, 33	555, 601				
488	Dirigold.....	Cu; Al, 10; Ni, 2	582				
489	Doctor metal.....	Cu, 88; Zn, 9.5; Sn, 2.5					
490	Dowmetal A.....	Mg, 92; Al, 8	544, 604				
491	Dowmetal B.....	Mg, 88; Al, 12	544				
492	Dowmetal C.....	Mg, 85; Al, 15	544				

Index No.	Name	Composition	Page	Index No.	Name	Composition	Page
536	Elanite.....	Similar to Duriron					
537	Elinvar (Key No. 277, p. 512)	Fe; Ni, 36; Cr, 12; C, 0.8; Mn; Si, 1-2; P; S	512				
538	Emperor brass.....	Cu, 60; Al, 20; Zn, 20		583	Grade	Max. Max. V Si C P S	
539	English alloy.....	Sn, 53; Pb, 33; Sb, 11; Cu, 2.4; Zn, 1			B.....	30-40 5-8 1.5-3 0.25 0.3	
540	English brass.....	Cu, 70; Zn, 29; Pb, 0.3; Sn, 0.2	469, 555, 601	584	C.....	35-45 >2 >1.5 0.15 0.2	
541	English phosphor bronze.....	Cu, 79; Sn, 10; Pb, 9.6; P, 1.0	562	585	D.....	35-45 >2 >0.75 0.10 0.1	
542	English nickel silver.....	Cu, 70; Zn, 29; Pb, 0.3; Sn, 0.2	469, 555, 601			Grades A-C, Al, >2; D, Al, >1	
543	English speculum.....	Cu, 67; Sn, 33	561	586	Ferrozoid.....	Fe; Ni; C (Ni steel)	
544	Engraver's brass.....	Cu, 66; Zn, 33; Pb, 1	469	587	Ferry alloy.....	Cu; Ni; Zn (Ni silver)	
545	Eureka.....	v. Manganin		588	Festel metal.....	Fe, 55; Co, 23; Cr, 21; C, 0.7	464
	Eutectic (fusible alloys).....	v. also p. 391		589	File metal (file bronze).....	Cu, 73-51; Sn, 18-31; Pb, 8.5-7; Zn, 0-10	561, 562
546	M. P. 70-74°C.....	Bi, 50; Pb, 27; Sn, 13; Cd, 10		590	Fire armor.....	Ni, 61; Fe, 20.5; Cr, 18.5	
547	M. P. 91.5°C.....	Bi, 52; Pb, 40; Cd, 8		591	Flame resisting alloy.....	Fe; Cr, 14; Ni, 9.7; Mn, 0.8; Si, 0.2; C, 0.2	
548	M. P. 96°C.....	Bi, 53; Pb, 32; Sn, 15		592	Flange metal (French).....	Cu, 94; Sn, 5.6; Pb, 0.05	559, 601
549	M. P. 103°C.....	Bi, 54; Sn, 26; Cd, 20		593	Flange metal (German).....	Cu, 92; Zn, 5; Sn, 2.5	
550	M. P. 145°C.....	Sn, 50; Pb, 32; Cd, 18		594	Fletcher and Emperor bearing.....	Al, 92; Cu, 7.5; Sn, 0.3	536, 601
551	Everbrite.....	Cu, 60-58; Ni, 35		595	Fletcher's alloy.....	Al, 96; Cu, 3; Sn, 1; Sb, 0.5; P-Sn, 5	
552	Everdur No. 50 metal.....	Cu, 94.5; Si, 4.5; Mn, 1	554	596	Flint alloy.....	Fe, 83; Cr, 12.5; Si, 0.5; C, 0.3	508, 603
553	Ex. B metal.....	Cu, 77; Pb, 15; Sn, 8; P	562	597	Fontainmoreau's bronze.....	Zn, 99-90; Cu, 0-8; Fe, 0-1; Pb, 1-0	465, 545
554	Excello (resistance).....	Ni, 85; Cr, 14; Fe, 0.5; Mn, 0.5	467, 480	598	Forbes metal.....	Zn, 54; Cu, 46	465, 546
555	Excelsior.....	Cu, 53; Ni, 45; Fe, 0.3	480, 601	599	Forging brass.....	Cu, 60-53; Zn, 40-43; Mn, 0-4.5	555, 556
556	Ex. K metal.....	Cu, 77; Pb, 12.5; Sn, 10.5; P	562	600	Fourdrinier wire.....	Cu, 85-80; Zn, 15-20; Sn, 0-0.4	469, 555
557	Expanding alloy.....	Pb, 67; Sn, 25; Bi, 8.3		601	Foundry pig iron*.....	Fe; C, 3-4; Si, 1.5-3; Mn, >1; P, 0.5-1; S, >0.04-0.06	
558	Extra soft steel.....	Fe; C, 0.2; Si, 1.3; Mn, 0.2; P; S	470, 488	602	Frary metal.....	Pb; Ba, <2; Ca, <1; Hg, 0.3	556
559	Fahlun brilliants (Faluner Diamanten).....	Sn, 60; Pb, 40	467, 557	603	Free cutting bronze.....	Cu, 89; Zn, 10; Pb, 1.5	469
560	Fahrig antifriction.....	Sn, 90; Cu, 10	561	604	Free-turning rod brass.....	Cu, 62; Zn, 35; Pb, 2.6; Fe	469
561	Fahrite, C-5.....	Fe; Cr, 25; C	508	605	French alloy.....	Cu, 58-50; Zn, 25-30; Ni, 17-20	480
562	Fahrite, N-1.....	Fe; Ni, 35; Cr, 17		606	French aluminium bronze (v. also Brolunick).....	Cu, 82; Al, 7; Ni, 5.5; Fe, 4; Mn, 2	
563	Fenton's alloy.....	Zn, 80; Sn, 15; Cu, 5		607	Freund steel.....	Fe; Si, 0.7-1.3; Mn, 0.3-0.6; C, 0.1-0.15; Cr	472, 523
564	Fermet.....	Fe; Ni, 18; Cr, 4; Mn, 2.2; W, 0.5-1; C, 0.4; Cu, 0.3		608	Frick's alloys.....	Cu, 69-50; Zn, 18-39; Ni, 5.5-31	475, 480
565	Ferro-carbon-titanium.....	Fe; Ti, <15; C, 1.5; Si, 1.4; Al, 0.8; Mn; P; S		609	Friction alloy (standard).....	Pb, 50; Sn, 40; Sb, 10	557
	Ferrochromium			610	Fusible alloys.....	v. p. 391	
566	A. S. T. M. Spec. A101-25T	Grade %C		611	Fusible tea spoons.....	Bi, 45; Sn, 17; Pb, 30; Hg, 5-10	
567		A 4-8 or S*	Cr, 60-75; Si; S*	612	"G" alloy (N.P.L.).....	Al; Zn, 18; Cu, 3; Si, 0.8; Mn 0.4; Mg, 0.3; Fe, 0.2	538
568		B 1.5-2		613	Gear bronze.....	Cu, 91-78; Sn, 8.5-13; Zn, 0-3; Pb, 0-2; P, 0-2 (v. also Index No. 1359)	560, 601
569		C 1-1.5	Fe, balance	614	Gear steel (high duty).....	Fe; Ni, 3.5; Cr, 1.5; C, 0.45-0.5	472, 512
570	Ferrocupralium.....	Cu, 81-75; Fe, 2-13.3; Al, 12.4-11.2		615	Gedges (Geages?) metal.....	Cu, 60; Zn, 39; Fe, 1.5	556, 602
571	Ferromanganese.....	Fe; Mn, 38-80; C, 5-7; S, >0.3; Si, 0.5-1; P, >0.1-1	473	616	Genelite.....	Cu; Pb; Sn; graphite, <40	
572	Ferromanganese (A. S. T. M. Spec. A99-25T)	Mn, <78; Fe, balance; C, >7.5; Si, >1.0; P, >0.35; S, >0.05; v. also Index Nos. 1312-1314		617	German silver:		
	Ferromolybdenum:†			618	Austrian (Gersdorf).....	Cu, 60-50; Zn, 20-25; Ni, 20-25	475, 482
573	Regular.....	Fe; Mo, 50-60; C, 2.0		619	Best.....	Cu, 46; Zn, 34; Ni, 20	480
574	Special.....	Fe; Mo, 50-60; C, 0.5		620	Birmingham.....	Cu, 62-50; Zn, 32-20; Ni, 12-30	480, 601
575	Ferronickel:			621	Common formula.....	Cu, 55; Zn, 25; Ni, 20	475, 480
	No. 193 alloy (Driver Harris)	Fe; Ni, 30; Cr, 2 (v. also p. 391)		622	Gilding.....	Cu, 95; Zn, 5; Pb; Fe	469, 555
576	Ferrosilicon (A. S. T. M. Spec. 100-25T)	Grade %Si		623	Gilding foil.....	Sn, 98; Cu, 2.2; Fe, 0.1	561
577		A 47-53	474	624	Gilding metal.....	Cu, 72-64; Zn, 23-34; Sn, 0.3-2.5; Pb, 0.3 (v. also Index Nos. 306, 333 and 1134)	469, 555
578		B 72-78	474	625	Glass mold alloy (U. S. patent 1 360 773)	Cu, 65-55; Ni, 12-18; Zn, 11-17; Fe, 8-12; Si, 0.5-1	
579	Ferrosilicon pig (silvery pig iron)	Fe; Si, 6-16; v. also Index No. 1233	474	626	Glievor bearing.....	Pb, 77; Sb, 14; Sn, 8; Fe, 1.5	476
	Ferrotitanium.....	v. Index No. 565		627	Glievor bearing.....	Zn, 74; Sb, 9; Sn, 6.7; Pb, 5; Cu, 4.4; Cd, 1.4	
580	Ferrotungsten.....	Fe; W, 70-85; C, 0.5; Mn; Si; P; S		628	Glowray.....	Similar to Chromel C	
581	Ferro-uranium.....	Fe; U, 30-40; Si, 2.5-4; C, 1; Ca; Mn; Cu; Al; P; S			Glyco.....	Pb, 81; Sb, 15; Sn, 4.5; As, 0.5	557
	Ferro-vanadium (A. S. T. M. Spec. 102-25T)				Glyco metal.....	Zn, 85.5; Sn, 5; Pb, 4.7; Cu, 2.4; Al, 2	
582	Grade	V Si C P S	Max. Max.				
	A.....	30-40 8-15 3-6 0.25 0.3					

\* As specified by purchaser.

† Climax Molybdenum Co.

\* Graded by Si content, S increases as Si decreases.



Index No.	Name	Composition	Page
629	Glyco turbo.....	Pb, 70; Sb, 22; Sn, 8	
	Gold:		
630	22 carat.....	Au, 92; Ag, 4.2; Cu, 4.2	
631	22 carat dental, dark.....	Au, 92; Ag, 4.9; Cu, 3.4	
632	20 carat.....	Au, 84; Ag, 8.3-11; Cu, 6-8.3	
633	18 carat.....	Au, 75; Ag, 10-20; Cu, 5-15	
634	16 carat.....	Au, 67; Cu, 8-27; Ag, 6.6-26	586
635	15 carat.....	Au, 62; Cu, 13; Ag, 11	
636	14 carat.....	Au, 58; Cu, 14-28; Ag, 4-28	586
637	14 carat dental.....	Au, 58; Ag, 30; Cu, 12	
638	10 carat.....	Au, 42; Cu, 38-46; Ag, 12-20	586
639	8 carat.....	Cu, 47; Au, 33; Ag, 20	586
	Gold solder:		
640	18 carat.....	Au, 75-63; Ag, 13-31; Cu, 6.3-12	
641	16 carat.....	Au, 75; Ag, 17; Cu, 8.3	
642	14 carat.....	Au, 50; Ag, 33; Cu, 17	
643	12 carat.....	Au, 50; Cu, 35; Ag, 15	586
644	10 carat.....	Au, 41; Ag, 37; Cu, 21; Brass, 0.6	
645	8 carat.....	Au, 40; Ag, 37; Cu, 23	586
646	Best.....	Au, 63; Ag, 23; Cu, 15	
647	Easy melt.....	Au, 55; Ag, 32; Cu, 14	
648	Very easy melt.....	Ag, 55; Cu, 29; Au, 12; Zn, 5.5	
649	Goldal.....	A dental alloy	
650	Gold imitation (DRP 47 380).....	Cu, 97.8; Al, 2; Au, 0.2	
651	Gold leaf metal.....	Cu, 84-66; Zn, 16-34; Pb, 0-0.4	469, 555
	Government (U. S.) bronze:		
652	Spec. G.....	Cu, 88; Sn, 10; Zn, 2	565, 572
653	Spec. H.....	Cu, 83; Sn, 14; Zn, 3; Pb, 0.8	
654	Substitute.....	Cu, 90; Sn, 6.5; Zn, 3; Pb, 0.5	563
655	Graney bronze.....	v. Gurney's bronze	
656	Granfin (cast iron).....	Fe; C, 2.2-2.6; Graphite, 1.7-2.1; Si, 2.3-2.5; Mn, 0.7-1; P, 0.45-0.6; S, 0.3	497, 527, 600, 608
657	Graphalloy.....	Graphite bearing-metal	
658	Graphite metal.....	Pb, 80; Sb, 20	475, 557
659	Graphite metal.....	Pb, 68; Sb, 17; Sn, 15	557
660	Green gold.....	Au, 75; Ag, 11-25; Cd, 13-0	
661	Grey cast iron.....	Fe; C, 2.5-4; Si, 1.3-2; Mn; P; S (fracture is gray due to free graphite)	464, 476, 497, 526, 600, 608
662	Grey gold.....	Au, 86; Fe, 5.7-17; Ag, 0-8.6	
663	Guillaume's metal.....	Cu, 64.3; Bi, 35.7 (name also applied to Invar type)	
	Guishibuichi.....	v. Shibu-ichi	
664	Gun metal.....	Cu, 95-71; Sn, 0-11; Pb, 0-13; Zn, 0-5; Fe, 0-1.4	476, 559-572, 601
665	Gun mount bronze.....	Cu, 80; Zn, 17; Sn, 3	
666	Gurley's metal.....	Cu, 86.5; Zn, 5.4; Sn, 5.4; Pb, 2.7	
	For B. E. S. A. Specifications	v. p. 386	
667	Gurney's bronze (Graney?).....	Cu, 76; Zn, 15; Sn, 9	
668	Guthrie's alloy.....	Bi, 47; Sn, 20; Pb, 19; Cd, 13	
669	Halberland alloy.....	Cu, 87; Zn, 13	469, 555
670	Half hard steel (Key No. 30, p. 495).....	Fe; C, 0.49; Si, 0.44; Mn, 0.34; P, 0.06; S, 0.04	470, 491, 495
671	H. A. L. H. steel.....	Similar to Stellite	
672	Hamilton metal.....	Zn, 93; Cu, 3.5; Pb, 3.1; Sb, 1.5; P-Sn, 5 (name also applied to Chrysorin)	
673	Hammonia metal.....	Sn, 65; Zn, 32; Cu, 3.3	
674	Hard aluminum.....	Al, 77; Zn, 12; Mg, 4.5 (v. also Index No. 682)	
675	Hard babbitt.....	Sn, 83; Cu, 8.4; Sb, 8.3	
676	Hard bearing.....	Pb, 98.7; Mg, 1.3 (U. S. patent 803 920)	556
677	Hard drawing brass.....	Cu, 62-59; Zn, 38; Pb, 0.06-3.4	469, 555, 601
678	Hard head.....	Sn, 90; Sb, 8; Cu, 2	476, 556
679	Hardite.....	Ni, 45; Cr, 15; Fe, 13; Sb, 10.6; Cu, 6; Zr, 4; Mo, 3.5; Mn, 2; Al, 0.9	
680	Hard lead.....	Pb-Sb; Pb-As; Pb-alkali metal or Pb-alkaline earth metal	475, 476, 556, 557
681	Hard phosphor bronze.....	Cu, 93; Sn, 7; P, 0.2	560, 601

Index No.	Name	Composition	Page
682	Hard sheet aluminum.....	Al, 99-98; Mn, 1-2	468, 542
683	Hardware bronze.....	Cu, 88; Zn, 9.5-12; Sn, 0-1.5; Pb, 0-1	469, 555
684	Hard zinc (Hartzink).....	Zn, 92; Fe, 5.3; Pb, 2.4; Cu, 0.1	
685	Harlington (Harrington?) bronze.....	Cu, 56; Zn, 43; Sn, 0.9; Fe, 0.6	470, 556
686	Harmonia bronze.....	Cu, 57-55; Zn, 40-41; Fe, 1.3-1.8; Pb, 0.4; Al; Sn	556
687	Haynes metal, soft.....	Co, 62; W, 28; Cr, 10	
688	Haynes metal, hard.....	Co, 45; W, 40; Cr, 15	
689	Haynes metal.....	Fe, 75-70; Cr, 20-30; Co, 5-25	
	Heat resistant alloys.....	For list, v. p. 391	
690	Heat resistant steel (U. S. patent 1 357 549).....	Fe, 70; Cr, 15; Co, 14; Mn, 0.5; Si, 0.5; C, 0.5	
691	Heavy axle bearing.....	Zn, 47; Sn, 38; Sb, 6; Pb, 4; Cu, 1	
692	Heavy bearing.....	Sn, 85; Cu, 7.5; Sb, 7.5	
693	Helmet metal (helmet bronze).....	Cu, 72-70; Zn, 28-30	555, 601
694	Hercules bronze.....	Cu, 86; Sn, 10; Al, 2.5; Zn, 2	
695	Hercules metal.....	Cu, 54; Zn, 36; Fe, 7.5; Al, 2.5	
696	Heusler's magnetic alloys.....	Cu, 70-61; Mn, 18-30; Al, 8-15; Pb, 4-0	
697	Most magnetic.....	Cu, 61; Mn, 26; Al, 13	
698	High carbon steel.....	Fe; C, 0.65-1.55; Mn; Si; P; S	492, 493, 600-608
	High manganese bronze.....	v. Index Nos. 430, 842	
699	High manganese nickel.....	Ni, 98-94; Mn, 2-6	473, 482
	High speed steel:		
700	Brit. patent 139 837.....	Fe; Mo, 6; Co, 6; Cr, 4; C, 0.6	
701	Brit. patent 144 326.....	Fe; Mo, 6-10; Cr, 3-6; Co, 0.5-2; U, 0.2-1; Mn, 0.2-0.4; Si, 0.2-0.4; C, 0.5-0.8	
702	U. S. patent 1 337 209.....	Fe; Mo, 6-10; Cr, 3-6; Mn, 0.2-0.4; Si, 0.2-0.4; C, 0.5-0.8	
703	U. S. patent 1 337 210.....	Fe; Mo, 3-10; Co, 1-5; V, 0.2; Mn, 1-2; Si, 0.1-0.3; C, 0.6-1.2	
704	High temperature bronze.....	Cu, 91; Zn, 6.3; Sn, 2.7; Pb, 1.3	
	High tensile brasses.....	For list, v. p. 389	
705	Hohenzollern brass.....	A high tensile brass	
706	Hooker brass.....	Cu, 61; Zn, 37; Pb, 2	469, 602
707	Hopkinson's alloy.....	Fe, 75; Ni, 24.5; Si; etc.	481
708	Hot rolling brass.....	v. Tube brass	
709	Hoyle's metal.....	Sn, 46; Pb, 42; Sb, 12	557
710	Hoyt metal.....	Pb, 94-90; Sb, 6-10	557
711	Huron metal, cast.....	Al; Cu, 6.6; Ni, 1.3; Mg, 0.5; Co, 0.3; (Mn + Sn + Cd), 0.5	536
712	Huron metal, rolled.....	Al; Cu, 3.5-4; Mg, 0.5; Mn, 0-0.6; Cr, 0.1-0.6	534
713	Husmann metal.....	Sn, 74; Sb, 11; Pb, 11; Cu, 4; Fe, 0.2; Zn, 0.2	
714	Hydraulic bronze.....	Cu, 83; Sn, 11; Zn, 6; Pb, 0.1	476, 565
715	Hydrone.....	Pb, 67; Sb, 33	
716	Ia-Ia.....	Cu, 60; Ni, 40	464, 480
717	Ideal, Elalco.....	Cu, 58-53; Ni, 40-45; Fe, 0.6-1; Mn, 0.5-1; Al	464, 480, 601, 606
718	Ignition pin alloy.....	Ce, 61; Fe, 37	
719	Ignition pin alloy.....	Ce, 73-70; Zn, 17-24; Fe, 1.6-6; Al, 0-2.4; Mn	
720	Illium.....	Ni, 63; Cr, 21; Cu, 6.5; Mo, 5; W, 2; Fe, 1; Mn, 1; Al, 1	
721	Immadium bronze.....	Manganese bronze with Al	
722	Imperial.....	Cu, 80; Ni, 20	480
723	Imperial steel.....	Fe; W, 6.4; Mn, 2.1; C, 1.6; Si	
724	Ingot iron.....	Fe, 99.9; C, 0.02; Mn; Si; P; S; v. also Armco iron	470, 487, 602, 606
725	Injector bronze.....	Cu, 84; Sn, 8.5; Zn, 5; Pb, 2.5	569
726	Instrument bronze.....	Cu, 82; Sn, 13; Zn, 5	
727	Invar.....	Fe, 64; Ni, 36; C, 0.15-0.2	471, 482
728	Iridosmine.....	v. Osmiridium	
	Iron.....	For lists of ferrous alloys v. pp. 390, 391	
729	Iron, electrolytic.....	Fe; C, <0.03; other impurities, <0.05	472, 478

Index No.	Name	Composition	Page	Index No.	Name	Composition	Page
730	Ironac.....	Fe; Si, 13; C, 1.1; Mn; P; S	473	785	Lead shot.....	Pb, 99.8; As, 0.2	
731	Iron bronze.....	Cu, 82.5; Sn, 8.6; Zn, 4.4; Fe, 4		786	Lead tape.....	Pb, 95; Sb, 4.5; Sn, 0.5	557
732	Ironier's bronze.....	Cu; Sn; Hg, 1		787	Lechesne (two patents, name usually applied to first composition)	Cu, 90-60; Ni, 10-40; Al, 0.2-0.05	480
733	Iserlohn (cast).....	Cu, 64; Zn, 34; Sn, 2.5; Pb, 0.3	556	788	} Ledebur's bearing alloys... {	Zn, 85; Sb, 10; Cu, 5	
734	Iserlohn (sheet).....	Cu, 70; Zn, 30	555, 601	789		Zn, 77; Sn, 18; Cu, 5.5	
735	Jacana metal.....	Pb, 70; Sb, 20; Sn, 10		790	Lemarquand's non-oxidizable alloy	Cu, 39; Zn, 37; Sn, 9; Co, 8; Ni, 7	
736	Jacoby metal.....	Sn, 85; Sb, 10; Cu, 5	476, 557		Le Mat's metal.....	v. Lutecin	
737	Jalcase steel.....	A case hardening steel		791	Liberty pistons.....	Al, 77; Zn, 21; Cu, 1.1; Fe, 0.5; Pb; Sn	538
738	Jewelers metal.....	Cu, 91.5-83; Zn, 6.5-17; Sn, 0-2	469, 555	792	Lichtenberg's alloy.....	Bi, 50; Pb, 30; Sn, 20	
	Kalchoids.....	Cu; Sn; Zn, alloy system		793	Liddel's alloys.....	Zn, 90-88; Cu, 6.5-5; Al, 6-5	546
739	} Kamarsch bearing alloys... {	Sn, 85; Sb, 5; Cu, 3.6; Bi, 1.6; Zn, 1.4		794	Linotype, cheap.....	Pb, 85; Sb, 11; Sn, 3.5	557
740		Sn, 71; Cu, 21; Sb, 7.2		795	Linotype, standard (English)...	Pb, 83; Sb, 12; Sn, 5	557
741		Sn, 71; Sb, 20; Cu, 9.5		796	Lipowitz alloy.....	Bi, 50; Pb, 27; Sn, 13; Cd, 10	
742	Karma.....	Ni, 80; Cr, 20	480, 608	797	Little's speculum.....	Al, 65; Sn, 31; Zn, 2.3; As, 1.9	
743	Keene's alloy.....	Cu, 75; Ni, 16; Sn, 2.8; Zn, 2.3; Co, 2; Fe, 1.5; Al, 0.5		798	L M Steel (United Alloy Steel Corp.)	Fe; Ni, 2.8-3.3; Cr, 0.7-0.9; Mo, 0.3-0.5; C, 0.2-0.4; Mn; Si; P; S	472, 605
744	Kienmayer's amalgam.....	Hg, 50; Sn, 25; Zn, 25		799	Low brass.....	Cu, 80; Zn, 20; Pb; Fe	555, 601
745	Kelmet.....	Cu, 70.5-68; Pb, 22.5-25.5; Sn, 6.4-6.6; S, 0.03; Zn, 0.03-0.04; Ni; Fe	562	800	Low carbon steel.....	Fe; C, > 0.25; Mn; Si; P; S	487-491
746	Kemlet.....	Zn, 67; Al, 15; Cu, 9	546	801	} Lowroff phosphor bronze... {	Cu, 70; Pb, 16; Sn, 13; P, 1	562
747	Kern's hydraulic bronze.....	Cu, 78; Sn, 12; Zn, 10	570, 572	802		Cu, 90; Pb, 5.5; Sn, 4; P, 0.5	561
748	K. L. steel (Böhler).....	Fe; W, 1.2; Cr, 1.0; C, 0.47	472	803	Lucerno.....	Ni, 68; Cu, 28; Fe, 2.4; Mn, 2.2	469, 480, 600, 608
749	Kneiss metal.....	Zn, 50-40; Pb, 25-42; Sn, 25-15; Cu, 0-3		804	Lucero.....	Ni, 65; Cu, 30; Mn, 5	604
750	Kochlin's bearing.....	Cu, 90; Sn, 10	475, 559	805	Ludlum.....	Fe; Cr, 13-17; Si, 1; Mo, 1; C, 0.4	
751	Koltchak (Koulchoog) aluminum	A Russian alloy similar to duralumin		806	Lumen (bronze).....	Zn, 86-85; Cu, 10; Al, 4-5	546
752	Kosmos.....	A dental alloy		807	Lurgimetall.....	Pb, 96.5; Ba, 2.8; Ca, 0.4; Na, 0.3	556
753	Kromax.....	Ni, 80; Cr, 20	480, 608	808	Lutecin (Le Mat's Paris metal)	Cu, 80; Ni, 16; Zn, 5; Fe, 5; Sn, 2; Co, 1	
754	Kromore.....	Ni, 85; Cr, 15	467, 480	809	Lynite, 109.....	Al, 89; Cu, 12-14; other elements, > 1	467, 534, 601
755	Krupp (Grosman) bearing.....	Al, 87; Cu, 8; Sn, 5		810	Lynite, 122.....	Al, 92; Cu, 9.3-11; other elements, > 2	467, 534, 601
756	Kruppin.....	Fe; Ni, 28; C	471, 482	811	Lynite, 146.....	Al, 93; Cu, 7-8.5; other elements, > 1.7	467, 534, 601
757	Krupp type metal.....	Pb, 60; Sb, 18; Sn, 12; Cu, 4.7; Ni, 4.7; Bi, 1		812	Lynite, body alloy.....	Al, 95; Cu, 5	534, 601
758	Krupp V1M steel.....	Fe; Cr, 14; Ni, 2.3; C, 0.1		813	Lynite, crank case.....	Al, 90; Cu, 7.8; Zn, 1.5; Fe, 1.3	536
759	Krupp V2A steel.....	Fe; Cr, 23; Ni, 9.5; C, 0.4		814	Lynite, piston.....	Al, 95; Cu, 2; Mg, 1.5; Fe, 0.8; Si, 0.2; Mn, 0.01	
760	K. S. magnet steel.....	Fe; Co, 30-40; W, 5-9; Cr, 1.5-3; C, 0.4-0.8		815	Lynite, piston.....	Al, 89; Cu, 11; Mg, 0.5	534
761	Kuhne's phosphor bronze.....	Cu, 78; Sn, 11; Pb, 10; P, 0.6; Ni, 0.3	562, 570	816	Lynx bronze.....	Cu, 89; Fe, 7.2; Al, 3.8	
762	Kunheim metal.....	Rare earth metals, 86*; Mg, 12; Al, 2			Lyons gold.....	v. Tombac	
763	L-5 alloy.....	Al, 85; Zn, 13-15; Cu, 2.5-3; Fe; Si	539-542, 537, 601	817	Machine bronze.....	Cu, 50; Ni, 25; Sn, 25	
764	L-8 alloy.....	Al, 88; Cu, 12; Fe; Si	534, 601	818	Machinery brass.....	Cu, 83; Zn, 16; Sn, 1	555
765	L-10 alloy.....	Al, 89; Cu, 10; Sn, 1; Fe; Si			Machine steel.....	v. Low-carbon steel	
766	L-11 alloy.....	Al; Cu, 6-8; Sn, 0-2; Zn, > 1; Fe; Si	467, 534, 601	819	Mach's alloy.....	Al, 98; Mg, 2-10	464, 542
767	Laderig's speculum.....	Cu, 69; Sn, 29	475, 559	820	Mach's speculum.....	Al, 69; Mg, 31	
768	Lafond's axle bearing.....	Cu, 80; Sn, 18; Zn, 2	475, 561	821	Macht's yellow metal.....	Cu, 57; Zn, 43	555, 602
769	Lafond's heavy bearing.....	Cu, 83; Sn, 15; Zn, 1.5; Pb, 0.5	475, 561	822	Mackenzie metal.....	Pb, 70-68; Sb, 17-16; Sn, 13-16	
770	Lafond's malleable bronze.....	Cu, 98; Sn, 1.9	559	823	Magnalite.....	Al; Cu, 2-2.6; Mg, 1.2-2; Ni, 0.7-2; Fe; Si; Sn; Zn	601, 608
771	Lafond's pump bronze.....	Cu, 88; Sn, 10; Zn, 2	565, 572	824	Magnalium (original).....	Al, 95-70; Mg, 5-30	464, 542
772	Lancashire brass.....	Cu, 73; Zn, 25; Pb, 2	469	825	Magnalium, cast.....	Al, 85; Mg, 15	464
773	Latten (Laiton).....	Yellow brass		826	Magnalium, cast x.....	Al, 95; Cu, 1.8; Mg, 1.6; Ni, 1.2	601, 608
774	Lautal.....	Al; Cu, 4; Si, 2; Fe		827	Magnalium, cast y.....	Al, 97; Cu, 1.8; Mg, 1.5; Sn and Pb	
775	Law's phosphor bronze.....	Cu, 89-88; Sn, 9.5-11; P, 0.7-1.0	560, 565, 570-572	828	Magnalium, cast z.....	Al, 95; Sn, 3.2; Mg, 1.6; Cu, 0.2; Pb, 0.7	
776	Lead alloy (for small castings).....	Sn, 75; Sb, 20; Pb, 5		829	Magnalium, sheet.....	Al, 95; Mg, 5	542, 601
	Lead bronzes.....	For list, v. p. 389			Magna metal.....	Same as Electron	
777	Leaded brass.....	Cu, 88-62; Zn, 10-35; Pb, 1.7-2.6; Fe	469	830	Magno, Elalco.....	Ni, 95; Mn, 5	473, 482
778	Leaded bronze.....	Cu, 88; Zn, 10; Pb, 1.5-1.7; Fe	469	831	Magnolia metal.....	Pb, 84-78; Sb, 15-16; Sn, 0.6; Bi, 0-0.3	557
779	Leaded gun metal.....	Gun metal + 1 % Pb	566, 569	832	Magno-nickel.....	Ni; Mn, 2-6	473, 482
780	Leaded low brass.....	Cu, 78; Zn, 20; Pb, 1.7; Fe	469	833	Major metal.....	Al; Cu, 3; Fe, 2; Zn, 0.4; Ni, 0.4; Si; Mg; Mn	
781	Leaded monel metal.....	Ni, 60; Cu, 32; Pb, 2.2; Fe, 2.2; Mn, 2.0; Si, 0.9; C, 0.2; S	469	834	Maillechort*.....	Cu, 67-65; Zn, 13.5; Ni, 13-19; Fe, 0.5-3.2; Sn; Pb	480
782	Leaded screw wire brass.....	Cu, 69; Zn, 30; Pb, 1.7; Fe	469				
783	Lead foil.....	Pb, 86; Fe, 6.9; Al, 5.5; Sn, 1.9					
784	Lead foil (Calin).....	Pb, 87; Sn, 13; Cu, 1					

\* Includes 2 % H.

\* French generic name.



Index No.	Name	Composition	Page
835	Malleable casting pig.....	Fe; C, 3-4; Si, 0.75-1.5; Mn, $\geq 1$ ; P, 0.2; S, $\geq 0.05$	
	Malleable cast iron:		
836	American "Black Heart"....	Fe; C, 2.8-3.5; graphite, Tr.; Si, 0.6-0.8; Mn, $<0.4$ ; P, $<0.2$ ; S, $<0.07$	476, 477, 497, 525, 526
837	European "Reamur".....	Fe; C, 2.8-3.5; graphite, Tr.; Si, 0.6-0.8; Mn, $<0.2$ ; P, $<0.2$ ; S, $<0.4$	476, 477, 497, 525, 526
838	Mallet alloy.....	Zn, 75; Cu, 25	465, 546
839	Malloydium.....	Cu, 60; Ni, 23; Zn, 13; Fe, 0.9	480
840	Maluminum.....	Al, 87; Cu, 6.4; Zn, 4.8; Fe, 1.4; Si, 0.2; Mn, 0.1; Pb, 0.2	
841	Mangaloy.....	Ni; Fe; Mn	
842	Manganese brass.....	Cu, 85-54; Zn, 2-40; Mn, 1-25; Fe, 0-2.4; Ni, 0-2.5; Al; Pb	556
843	Manganese bronze.....	Cu, 86-82; Sn, 6-17; Mn, 0.2-2.7; Zn, 0-5; Pb, 0-3	
844	Mn-Bronze Mn-c (cast).....	Cu, 58; Zn, 40; Mn, 2	556
845	Mn-Bronze Mn-r (rolled).....	Cu, 59; Zn, 31; Sn, 1; Mn, 0.3. (The last two, like most alloys called Mn bronzes are really Mn brasses.)	556
846	Manganese copper.....	Cu, 90-56; Mn, 8.7-41; Fe, 0-2.7; Zn, 0-2; Sn; Si; Pb	
847	Manganese copper.....	Mn, 52; Cu, 29; Fe, 9.7; Al, 6.3	
848	Manganese nickel.....	Ni, 98.5-95; Mn, 1.5-5; Fe	473, 482
849	No. 473 alloy.....	Ni, 96; Mn, 4 (Driver Harris)	473, 482
850	No. 484 alloy.....	Ni, 98.5; Mn, 1.5 (Hoskins)	473, 482
851	Manganese nickel.....	Cu, 82-52; Mn, 14-31; Ni, 3-16	
852	Manganese nickel brass.....	Cu, 65-51; Zn, 5-40; Ni, 2-18; Mn, 1.5-20; Al; Fe; Sn; Pb	
853	Manganese nickel silver.....	Cu, 73-60; Mn, 2.4-20; Ni, 10-17; Sn, 0-10; Zn, 0-8.8	
	Manganese steel:		
854	Brit. patent 131 980 (pearlitic)	Fe; Mn, 1.4-3.5; Si, 0.2-0.3; C, 0.2-0.6; P; S	471, 520-523
855	Hadfield's (austenitic).....	Fe; Mn, 11-14; C, 1-1.3; Si, 0.3-0.8; P, 0.05-0.08; S, very low	471, 520-523
856	Manganin.....	Cu, 53; Zn, 39; Sn, 2.7; Ni, 2.5; Mn, 1.7; Al, 0.2	
857	Manganin.....	Cu, 70; Mn, 25; Ni, 5	
858	Manganin.....	Cu, 86-82; Mn, 4-15; Ni, 2-12; Fe	
859	Mangan-Neusilber.....	Cu, 73-59; Ni, 10-18; Mn, 2.4-20; Zn, 5-20	
860	Manhardts alloy.....	Al, 83; Sn, 10; Cu, 6.2; P; Mg, 0.1	
861	Mannheim gold.....	Cu, 89-80; Zn, 7-12; Sn, 0-9.3; P-Sn, 0-5	556, 561, 563, 565
862	Marine babbitt.....	Pb, 72; Sn, 21; Sb, 7	
863	Markus alloy.....	Cu; Ni; Zn	
864	Marsh's patent.....	Ni, 75; Cr, 25	
865	Marties' non-oxidizable alloy..	Ni, 35; Zn, 18; Cu, 17; Fe, 10; Sn, 10	
866	Martin steel (hard) (Key No. 48, p. 492)	Fe; C, 0.73; Si, 0.4; Mn; P; S	492, 523, 602
867	Mathesius metal (U. S. P. 1 549 137)	Pb; Ca, 3; other alkaline earth metals, 1-2	556
868	Matrix brass.....	Cu, 62; Zn, 37; Pb, 1.5	469, 602
869	Matrix metal.....	v. Index Nos. 794, 795, 910, 1351-1353, 1426-1429	
870	Mayari cast iron.....	Mayari pig recast by itself or added to gray cast iron	
871	Mayari pig.....	Fe; Cr, 2.5-3; Ni, 1.3-1.5; C	
872	Mayari steel.....	Fe; Ni, 1-1.5; Cr, 0.2-0.7; P, low	510, 605-607
873	McAdamite.....	Al; Zn, 12-18; Cu, 3.1; Mg, 0.2	537, 601

Index No.	Name	Composition	Page
874	McAdams, W. A., alloys..	Al, 82; Cu, 12; Cd, 5; Ag, 1	
875		Al, 80; Sn, 8; Cd, 8; Ag, 4	
876		Al, 70; Zn, 22; Sb, 5; Cu, 3	
877		Al, 70; Zn, 26; Cu, 3; Ag, 1	
878		Al, 69; Zn, 23; Cu, 7.7; Ni, 0.6	
879	McFarland and Harder alloys	Al, 60; Zn, 20; Ag, 17; Cu, 5	
880		Ni, 59-29; Cu, 11-55; Cr, 10-43	
881	McKechnie's bronze.....	Cu, 57; Sn, 41; Zn, 1; Fe, 1; Pb, 0.5	
	McKinney alloys:		
882	Cast.....	Al, 96; Cu, 2; Mn, 1.5	534
883	Hard forging.....	Al, 95; Cu, 3; Mn, 2	534
884	Soft forging.....	Al, 97; Cu, 2; Mn, 1	534
885	McLure alloy.....	Al, 85; Cu, 8.2; Sn, 5-6; Fe, 0.9; Si, 0.3; Mn, 0.2; Mg; Ni; Zn	
886	Meco.....	Cu, 50; Ni, 25; Zn, 20; ?, 5	
887	Medal bronze.....	Cu, 97-92; Sn, 1-8; Zn, 0-2	559, 601
888	Medal metal.....	Cu, 84; Zn, 16	555
889	Medium steel.....	Fe; C, 0.30-0.60	489-491
890	Metalline.....	Co, 35; Cu, 30; Al, 25; Fe, 10	
891	Meteorite.....	Al, 98-94; P, 1-4; Zn, 1-2	
892	Meteor steel.....	A nickel steel	
	Mild steel.....	v. Low carbon steel	
893	Minargent.....	Cu, 57-46; Ni, 40-32; Pb, 0-22; W, 2.8-0; Al	
894	Minofor.....	Sn, 69-66; Sb, 18-20; Zn, 9-10; Cu, 3-4	
895	Mira metal.....	Cu, 75; Pb, 16; Sb, 6.8; Sn, 0.9; Zn, 0.6; Fe, 0.4; Co; Ni, 0.2	
896	Misch metal.....	Ce, 60-50; La, 25; (Dy, Sa, etc.), 15; Fe, 1-2	
897	Misco metal.....	Fe, 57.5; Ni, 25; Cr, 15; Si, 1.5; Mn, 0.5; C, 0.5	604
898	Mitis iron*.....	Fe; C; Al, 0.06-0.27	529
899	M-M-M (modified monel metal)	Ni, 65-60; Cu, 24-27; Sn, 9-11; (Fe + Mn + Si), 1-3	
900	Mo-1 Steel†.....	Fe; Cr, 0.7-1; Mo, 0.25-1; C, 0.15-0.23; Mn, 0.4-0.7; Si, 0.1-0.2	472, 605
901	Mo-2 Steel†.....	Fe; Cr, 0.8-1.1; Mo, 0.25-1; C, 0.23-0.3; Mn, 0.5-0.8; Si, 0.1-0.2	472, 605
902	Mo-3 Steel†.....	Fe; Cr, 0.8-1.1; Mo, 0.25-1; C, 0.3-0.4; Mn, 0.5-0.8; Si, 0.1-0.2	472, 605
903	Mock gold.....	Cu, 80-67; Pt, 20-29; Zn, 0-4	
904	Moek gold.....	Ni, 6; Pt, 1; Ag, 1; Brass, 1	
905	Mock silver.....	Al, 84; Sn, 10; Cu, 5.5; P, 0.1	
	Modified Monel metal.....	v. M-M-M	
	Modified "Y" alloy.....	v. Index No. 1491	
906	Molybdenum steel.....	Fe; Mo, 0.3-3; C, 0.1-0.45; Mn, 0.6-1.3; Si, 0.3-0.5	472, 605
907	Mond 70.....	Ni, 70; Cu, 26; Mn, 4	480, 604
908	Monel metal (cast).....	Ni, 68; Cu, 28; Fe, 1.9; Si, 1.1; Mn, 0.3; C, 0.18; S	408, 469
909	Monel metal (rods).....	Ni, 68; Cu, 28; Fe, 2.0; Si, 0.2; Mn, 1.8; C, 0.26; S	408, 469, 604, 606
910	Monotype, standard.....	Pb, 74; Sb, 18; Sn, 8	
911	Montanium.....	Al; Cu, 2.5-3.5; Mg, 0.5	534, 601
912	Morin's Chinese bronze.....	Cu, 83; Pb, 10; Sn, 5; Zn, 2	561
913	Mosaic gold (Ormolu).....	Cu, 63; Zn, 35	555, 601
914	Mousset's silver.....	Cu, 60; Ag, 28; Zn, 10; Ni, 3.5	
915	MS Steel (Climax Molybdenum Co.)	Fe; Cr, 0.8-1.1; Mo, 0.3-0.4; Mn, 0.6-0.9; C, 0.4-0.6	472, 605
916	Mudge's speculum.....	Cu, 69; Sn, 31	559, 561
917	Mumetal.....	Ni, 74; Fe, 20; Cu, 5.3; Mn, 0.7	
918	Muntz metal.....	Cu, 60; Zn, 40	555, 600
919	Muntz patents.....	Cu, 63-56; Zn, 37-42; Pb, 0-4	555, 602
920	Murman's alloy.....	Al, 72; Zn, 15; Mg, 14	

\* Wrought iron, melted, deoxidized with Al and cast with or without adding C.  
† Climax Molybdenum Co. Made in three Mo-range classes: A: Mo, 0.25-0.4; B: Mo, 0.5-0.75; C: Mo, 0.75-1.

Index No.	Name	Composition	Page	Index No.	Name	Composition	Page
921	Murman's alloy.....	Al, 92; Zn, 4.4; Mg, 3.6		969	Nickel bronze.....	Cu, 47; Sn, 10; Ni, 3; P-Sn, 1.0	
922	Musket steel.....	Fe; W, 6-8.2; Mn, 0.2-2.6; Si, 0.1-1.6; C, 2.0-2.3		970	Nickel cerium steel.....	Fe; Ni, 2.2-3; Ce, 0.1-0.9; C, 0.4-0.75; Mn; Si	531, 605
923	M. W. metal.....	Similar to Electron		971	Nickel-chrome	superior..... Ni; Cr, 19.5; Fe, 0.5; Mn, 2; C, 0.2	480
924	Mystic metal.....	Pb, 89; Sn, 11; Bi, 0.1		972		peerless..... Ni; Cr, 16.5; Fe, 3.0; Mn, 2; C, 0.1	480
925	Naval aluminum.....	Al; Cu, 1.5; Mn, 0.9; Ni, 0.4; Fe; Si		973		premier..... Ni; Fe, 25; Cr, 11; Mn, 3	480
926	Naval brass.....	Cu, 66-59; Zn, 32-40; Sn, 1.2-0.5; Fe; Pb (v. also Tobin bronze)	470, 556, 602		Nickel-chromium steel.....	v. Chrome-nickel steel	
927	Naval brass, N-c.....	Cu, 61; Zn, 38; Sn, 1	556, 602	974	Nickel-chromium cast iron.....	Fe; C, 3-4; Ni, 0.4-5; Cr, 0-0.5; Si; Mn; P; S	
928	Naval bronze, No. 4.....	Pb, 44; Sn, 36; Sb, 16; Cu, 4		975	Nickel coinage* (U. S. A.).....	Cu, 75; Ni, 25	480
929	Naval journal bearing: Spec. H.....	Cu, 83; Sn, 14; Zn, 3.5		976	Nickel-copper steel.....	Fe; Ni, 1-25; Cu, 0.4-10; C, 0.15-0.8; Mn; Si; P; S	513
930	Naval journal bearing: Spec. HX.....	Cu, 83; Sn, 14; Pb, 3.5	561	977	Nickelene.....	Cu, 55; Zn, 21; Ni, 13; Pb, 10; Sn, 2	
931	Naval phosphor bronze: P-c (cast).....	Cu, 88; Sn, 8; Zn, 2.5; P, 0.5	563	978	Nickeline.....	Cu, 75-55; Ni, 18-32; Zn, 0-20; Fe; Pb	475, 480, 601, 606
932	Naval phosphor bronze: P-r (rolled).....	Cu, 95; Sn, 4.5; P, 0.5	560, 601	979	Nickel-manganese bronze.....	Cu, 53; Zn, 39; Sn, 2.6; Ni, 2.5; Mn, 1.7; Al; Pb (v. also Index No. 842)	556
933	Naval valve bronze, M.....	Cu, 87; Sn, 7; Zn, 6	565	980	Nickel-molybdenum steel.....	Fe; Ni, 1.5-3; Mo, 0.1-0.7; C, 0.4; Mn; Si; P; S	604, 605
934	Navy aluminum bronze.....	Cu, 87-85; Al, 7-9; Fe, 2.5-4.5	578, 601, 606	981	Nickel oreide.....	Cu, 63-66; Zn, 31-33; Ni, 2-6	
935	Navy bearing.....	Sn, 91-80; Sb, 4.5-15; Cu, 3.7-5	557	982	Nickel oreide.....	Cu, 87; Ni, 6.7; Zn, 6.7	
936	Needle metal.....	Cu, 85; Sn, 8; Zn, 5.3; Pb, 1.7	565	983	Nickeloy.....	Al, 94; Cu, 4.2; Ni, 1.4	534
937	Neogen.....	Cu, 58; Zn, 27; Ni, 12; Sn, 2; Al, 0.5; Bi, 0.5		984	Nickel-silicon steel.....	Fe; Ni, 2.8-3.3; Si, 0.5-2.2; C, 0.35-0.5; Mn; P; S; Al	472, 605
938	Nergandin.....	Cu, 70; Zn, 28; Pb, 2	469		Nickel silver:		
939	Neusilber.....	Nickel silver		985	10 %.....	Cu, 65-56; Zn, 25-34; Ni, 10	480, 601
940	Nevada silver.....	Nickel silver		986	14 %.....	Cu, 60-56; Zn, 26-28; Ni, 14	480
941	Nevastain.....	Fe; Cr, 9.5; Si, 3.8; C, 0.4		987	15 %.....	Cu, 64-57; Zn, 21-28; Ni, 15	475, 480
942	New capital steel.....	Fe; W, 14; Cr, 3.7; V, 0.1; C, 0.6; Mn; Si; P; S	472	988	18 %.....	Cu, 65-55; Zn, 17-27; Ni, 18	475, 480
943	Newloy.....	Cu, 64; Ni, 35; Sn, 1		989	20 %.....	Cu, 64-53; Zn, 16-27; Ni, 20	475, 480
944	Newton's alloy (fusible).....	Bi, 50; Sn, 19; Pb, 31		990	25 %.....	Cu, 55; Ni, 25; Zn, 20	475, 480
945	N. G. F. alloy (U. S. Naval gun factory).....	Al; Cu, 1-1.5; Mn, 0.75-2; Fe, > 0.5; Si, > 0.1	534	991	30 %.....	Cu, 65-47; Zn, 5-23; Ni, 30	475, 480
946	Nichroloy I.....	Ni, 75; Cr, 16; Fe, 8; Mn, 3		992	Casting.....	Cu, 70-56; Ni, 13-20; Zn, 5.6-24; Sn, 0-4; Pb, 0-3.5	601
947	Nichroloy II.....	Fe, 50; Ni, 40; Cr, 7; Mn, 3 (Index Nos. 946 and 947 for wire or ribbon)		993	Cupping, drawing, milling, spinning.....	Cu, 59-54; Zn, 22-31; Ni, 12-20; Pb, 0-1	480
948	Nichroloy (cast).....	Fe, 50; Ni, 23; Cr, 20; Mn, 1; C, 1; V, 1; Si; Al		994	Rolling.....	Cu, 49; Zn, 39; Ni, 12	480
949	Nichrome.....	Ni, 80-54; Cr, 10-22; Fe, 4.8-27; Cu, 0-11; Mn, 0-2; C; Si; Ti; Mo	467	995	Turning.....	Cu, 65-59; Zn, 22-29; Ni, 12; Pb, 0-5	480
950	Nichrome I.....	Ni, 60; Fe, 25; Cr, 11; Mn, 4	480		Nickel steel:		
951	Nichrome II (wire or ribbon).....	Ni, 75; Fe, 12; Cr, 11; Mn, 2		996	Austenitic, above.....	Ni, 29; C, 0 to Ni, 0; C, 1.65	471,
952	Nichrome II (cast).....	Ni, 67-65; Cr, 20-22; Fe, 12-14; Mn, 1.5-2		997	Martensitic, between.....	Ni, 29; C, 0 to Ni, 0; C, 1.65	481,
953	Nichrome III.....	Ni, 85; Cr, 15	467, 480			Ni, 13; C, 0 to Ni, 0; C, 1.65	482,
954	Nichrome IV.....	Ni, 80; Cr, 20	480, 608	998	Pearlitic, between.....	Ni, 13; C, 0 to Ni, 0; C, 1.65	600-
955	Ni-chro-zink.....	A die-casting alloy				Ni, 0; C, 0 to Ni, 0; C, 1.65	608
		%      Hundredths      of %		999	Cementitic.....	C, > 1.65	
	Nickel (commercial):	Ni + Co		1000	Brit. patent 133 069.....	Fe; Ni, 2.8; Mn, 0.9; Cr, 0.4; Mo, 0.3; Si, 0.3; Ti, 0.1; C, 0.2	
956	Electrolytic.....	99.80	4	1001	Carpenter high Ni.....	Fe; Ni, 23-30	471, 482
957	Ingot or pig.....	99.20	30	1002	Nickel-tungsten.....	W, 75-50; Ni, 25-50	
958	Malleable (INCO).....	99.00	15	1003	Nickel-uranium steel.....	Fe; Ni, 0.3-0.4; U, 0.2-0.4; C, 0.2-0.8	478
959	Malleable B (INCO).....	98.75	175	1004	Nickel-vanadium steel.....	Fe; Ni, 3-3.3; V, 0.1-0.45; C, 0, 36; Si, 2.4; Mn; P; S	513, 605
960	Malleable C (INCO).....	96.75	175	1005	Nickel-zirconium.....	Ni, 86; Si, 6; Zr, 1.5; C, 0.1	
961	Reduced Ni (INCO).....	97.80	26	1006	Nickel-zirconium steel.....	Fe; Ni, 3; Zr, 0.24; C, 0.4; Si, 2.4; Mn; P; S	532, 605
962	Shot:			1007	Ni-Cr-Al.....	Ni, 88; Al, 12; Cr, 8	
	X (alloying).....	99.15	18	1008	Ni-Cr-Cu.....	Ni, 85-80; Cr, 20-25; Cu, 15-20	
	A (for anodes).....	98.75	18	1009	Nicu steel.....	Fe; Ni, 2.2; Mn, 0.6; Cu, 0.5; C, 0.3	513
	F.....	91.75	20	1010	NM steel†.....	Fe; Ni, 3-5; Mo, 0.3-0.7; C, 0.2-0.4; Mn, 0.3-0.5; Si, 0.1-0.2	605
	D nickel.....	v. Magno-nickel		1011	Noheet.....	Pb, 98; Na, 1.4; Sb, 0.11; Sn, 0.1	556
	Nickel-aluminum.....	v. Aluminum-nickel					
963	Nickel-aluminum bronze.....	Cu, 88; Ni, 10; Al, 2					
964	Nickel-aluminum bronze.....	Ni, 40; Al, 30; Sn, 20; Cu, 10					
965	Nickel bearing.....	Cu, 50; Ni, 25; Sn, 25					
966	Nickel brass.....	Cu, 50-54; Zn, 35-44; Ni, 1.5-15; Al; Fe					
967	Nickel boron steel.....	Fe; Ni, 2.8-3.6; B, 0.1-0.5; C, 0.15-0.7; Mn; Si; Al	530				
968	Nickel bronze.....	Cu, 62-47; Ni, 12-31; Zn, 11-21; Pb, 0-18; Sn, 1-8; Bi, 0-0.1					

\* Certain European coins are made of commercially pure Ni.

† Carbon Steel Co. and Climax Molybdenum Co.



Index No.	Name	Composition	Page
1012	Nongran.....	Cu, 87; Sn, 11; Zn, 2-3; P	565
1013	Non-oxidizable (U. S. patent 1 333 151)	Fe, 62; Cr, 25; Mn, 10; C, 1.1; Si, 0.95	
1014	Non-pareil.....	Pb, 78; Sb, 17; Sn, 5	557
1015	Novo steel.....	Fe; W, 19; Cr, 2.9; C, 0.6	472
1016	N. P. L. alloy ("Y" alloy) ....	Al, 93; Ni, 2; Mg, 1.5	534, 601
1017	Non-shrinking (patent)	Pb, 87; Sb, 6; Sn, 6; Cd, 1.3.	
	Numbered alloys.....	For the following alloys known by a number (No. 12, No. 193, No. 300, No. 473, No. 484), <i>v.</i> Index Nos. 66, 450, 575, 849, 850, <i>respt.</i>	
1018	Nürnberg gold.....	Cu; Al, 2-7.5; Au, 0.2-2.5	
1019	Oil hardening steel.....	Fe; Mn, 1.3-1.8; C, 0.8-1; Si, 0.3-0.4	471, 521, 522
1020	Oker (cast).....	Cu, 72; Zn, 24; Fe, 2.3; Pb, 1.1	
1021	Oker (sheet).....	Cu, 55; Zn, 45; Sn, 0.5	470, 556
1022	Oker I (sheet).....	Cu, 69; Zn, 30; Pb, 0.97	469
1023	Onion's alloy.....	Bi, 50; Pb, 30; Sn, 20	
1024	Optical bronze.....	Cu, 89; Zn, 6.5; Sn, 4.5	476
1025	Optical wire.....	Cu, 54; Zn, 28; Ni, 18	480
1026	Oranium bronze H.....	Cu, 90; Al, 10	575, 601
1027	Oranium bronze M.....	Cu, 95; Al, 5	574, 600
1028	Oranium bronze MH.....	Cu, 92; Al, 8	574, 600
1029	Oranium bronze S.....	Cu, 97; Al, 3	574, 600
1030	Oréide (French gold).....	Cu, 90-81; Zn, 10-15; Sn, 0-4.9; Pb	555
1031	Oréide, Brunswick.....	Cu, 68; Zn, 32; Sn, 0.5	556
1032	Ormulu* (Or moulu).....	Cu, 58; Zn, 23; Sn, 17	
1033	Ormulu, large.....	Cu, 91; Sn, 6.5; Zn, 3	476, 563
1034	Ormulu, small.....	Cu, 94; Sn, 5.9	559, 601
	Osmiridium (natural):		
1035	Nevyanskite.....	Ir, 58-44; Os, 27-49; Pt, 0-10; Ru, 0-6; Rh, 1.5-3; Pd; Fe; Cu	
1036	Siserskite.....	Os, 57; (Rh + Ir), 34; Ru, 8; Pt; Pd; Au; Fe; Cu	
1037	Otto's speculum.....	Cu, 69; Sn, 32	559, 561
1038	Ounce metal.....	Cu, 85; Pb, 5; Sn, 5; Zn, 5	561
1039	"P" alloy.....	Al; Fe, 0.11; Si, 0.11	533, 599
	Packfong.....	<i>v.</i> Paktong	
1040	Packing.....	Pb, 82; Sn, 4.8 ( <i>v. also</i> Index No. 56)	467, 557
1041	Packing, piston.....	Pb, 73-76; Sn, 12-14; Sb, 10-15	
1042	Packing, valve.....	Sn, 71; Sb, 24; Cu, 5	
1043	Packing, valve rod.....	Sn, 82; Sb, 10; Cu, 8	
1044	Packing (Russian).....	Zn, 99; Sn, 0.9; Pb, 0.3; Fe, 0.2	462, 545, 546
1045	Paktong (Pai t'ung or white copper)	Ni, 41-32; Cu, 26-40; Zn, 16-37; Fe, 0-2.6	480
1046	Palau.....	Au, 80; Pd, 20	
1047	Palau.....	Ni, 60; Pt, 20; Pd, 10; V, 10	
1048	Palau.....	Au; Ir	
1049	Pale yellow gold.....	Au, 92; Ag, 0-8.3; Fe, 8.3-0	
1050	Palladium alloy.....	Pd, 90; Rh, 10	
1051	Palladium alloy.....	Pd, 67; Ag, 33	585
1052	Palladium gold.....	Au, 90; Pd, 10	
1053	Palladium gold.....	Cu, 40; Au, 31; Ag, 19; Pd, 10	
1054	Parisian alloy.....	Cu, 69; Ni, 19.5; Zn, 6.5; Cd, 5	
1055	Paris metal.....	<i>v.</i> Lutecin	
1056	Parker's chrome alloy.....	Cu, 60; Zn, 20; Ni, 10; Cr, 10	
1057	Parr.....	Ni, 80; Cr, 15; Cu, 5	
1058	Parr.....	Ni, 67; Cr, 18; Cu, 8.5; W, 3.3; Al, 2; Mn, 1; Ti, 0.2; B, 0.2	
1059	Parson's manganese bronze....	Cu, 60; Zn, 35; Mn, 2-3; Fe, 1.2; Sn, 0.9; Pb, 0.4; Al, 0.2	556
1060	} Parson's white brass.....	Sn, 81-76; Sb, 6-11; Cu, 4.5-5; Pb, 3.5-13	
1061		Sn, 65-60; Zn, 30-35; Cu, 5	
1062	Partinium.....	Al, 96; Sb, 2.4; W, 0.8; Cu, 0.6; Sn, 0.2	
1063	Partinium.....	Al, 89; Cu, 7.4; Zn, 1.7; Fe, 1.3; Si, 1.1	

\* Also gilded bronze, brass or copper.

Index No.	Name	Composition	Page
1064	Pattern alloy.....	Al, 90; Cu, 8; Sn, 2	536
1065	Pattern alloy.....	Pb, 87; Sb, 13	475, 557
	Pearlitic cast iron.....	<i>v.</i> Index Nos. 1071, 1072	
1066	Pen metal.....	Au, 67; Cu, 25; Ag, 8; <i>v. also</i> Index Nos. 410, 411, 1317	586
1067	Pen metal.....	Cu, 85; Zn, 13; Sn, 2	555
1068	Percit.....	Similar to Stellite	
1069	Percussion cap brass.....	Cu, 95; Zn, 5	469, 555
1070	Percy Al bronze.....	Cu, 90-86; Al, 7.5-13; Pb, 0-2; Mn, 0-1.5	
1071	Perlit cast iron (Perlitguss)...	Fe; (C + Si), 3.4-4.6; Mn; P; S*	
1072	Perlit nickel cast iron.....	Fe; C, 1.7-3; Si, < 1; Ni; Mn; P; S†	
1073	Permalloy.....	Ni, 78; Fe, 21; Co, 0.4; Mn, 0.2; Cu, 0.1; C, 0.04; S, 0.04; Si, 0.03	
1074	Permanite.....	A cobalt steel	
1075	Pewter.....	Sn, 89-74; Pb, 0-20; Sb, 0-7.6; Cu, 0-3.5; Zn	557
1076	Pewter ( <i>v. also</i> Berthier's alloy)	Sn, 85; Cu, 6.8; Bi, 6; Sb, 1.7	
1077	Pewter, cast gilt.....	Cu, 65-64; Zn, 32-34; Pb, 0.3-2.9; Sn, 0.2-2.5	556, 600
1078	Pewter, for clock work.....	Cu, 61-60; Zn, 31-37; Sn, 1.4; Pb, 0.7-0.9	556, 602
1079	Phenix.....	Fe, 75; Ni, 25	471, 481
1080	Phono-electric wire.....	Cu, 98.55; Sn, 1.40; Si, 0.05	559
	Phosphor bronze:		
1081	Rolling.....	Cu, 96; Sn, 4.5; P, 0.1	464,
1082	Sheet.....	Cu, 95; Sn, 4-5; P, 0.5-1.0	560,
1083	Wire.....	Cu, 99; Sn, 1.2; P, 0.05 ( <i>v. also</i> p. 389)	565, 601
	For B. E. S. A. Specifications	<i>v.</i> p. 386	
1084	Phosphor copper A. S. T. M. Spec. B52-24T	P + Cu, <99.75; P, <14 (grade A) or <10 (grade B); Fe, > 0.15	
1085	Phosphor tin A. S. T. M. Spec. B51-24T	Sn, 90-95; P, 5-10; P + Sn, <99.50; P, <3.5	
1086	Pierrot metal, Beugnot.....	Zn, 83; Cu, 8.3; Sn, 7.6; Sb, 3.5; Pb, 3	
1087	Pinchbeck.....	Cu, 83-94; Zn, 6.4-17	469, 555
1088	Pin wire brass.....	Cu, 61; Zn, 39	555, 601
1089	Pioneer metal.....	Fe; Ni, 35; Cu, 25; Mo, <5; C, 0.2-0.5	
1090	Pirsch's German silver ( <i>v. also</i> Index No. 198)	Cu, 80-71; Ni, 16-17; Zn, 1-7.5; Sb, 1-2.8; Co, 1-2; Fe, 1-1.5; Al, 0-0.5	
1091	Piston rings, Seraing.....	Cu, 89; Zn, 9; Sn, 2	555
1092	Piston rings, Stephenson.....	Cu, 84; Zn, 8.3; Pb, 4.3; Sn, 2.9; Fe, 0.4	
1093	Placet.....	Ni, 60; Fe, 20; Cr, 15; Mn, 5	
	Plastic bronze.....	<i>v.</i> Ajax plastic bronze (name also generally applied to Cu; Pb; Sn alloys)	
1094	Plastic metal.....	Sn, 81; Cu, 9.5; Sb, 8.6; Fe, 1.4	
1095	Platalargan.....	Pt; Al; Ag	
1096	Platine.....	Zn, 57; Cu, 43	465, 546
1097	Platine-au-titre.....	Ag, 83-65; Pt, 17-35	474, 588
1098	Platiniridium (natural).....	Pt, 55; Ir, 28; Rh, 7; Cu, 3; Fe, 4; Pd; As	
1099	Platinite.....	Fe, 54-58; Ni, 46-42; C, 0.15	465, 482
1100	Platinoid.....	Cu, 60; Zn, 24; Ni, 14; W, 1-2	
1101	Platinoid.....	Cu, 54; Ni, 25; Zn, 20; Fe, 0.5; Mn, 0.2	475, 480
1102	Platinor.....	Cu, 45; Pt, 18; Brass, 18; Ag, 9; Ni, 9	
1103	Platinum alloy.....	Ag, 2-5 parts; Pt, 1 part; Cu, > 1 part	
1104	} Platinum gold, almost white{	Au, 70; Pt, 30	585
1105		Pt, 58; Ag, 25; Au, 17	
1106	Platinum gold, white.....	Au, 60; Pt, 40	585
1107	Platinum-iridium.....	Pt, 100-80; Ir, 0-20	467, 588
1108	Platinum lead.....	<i>v.</i> Birmingham platinum	
1109	Platinum-rhodium for thermocouples.....	Pt, 100-80; Rh, 0-20	467, 588

\* Pearlitic structure produced by using preheated molds according to U. S. P. 1 544 562.

† Sufficient Ni to precipitate graphite according to U. S. P. 1 564 284.

Index No.	Name	Composition	Page	Index No.	Name	Composition	Page
1110	Platinum silver.....	Ag, 66.7; Pt, 33.3	474, 588	1162	Regulus of Venus.....	Cu, 50; Sb, 50	464
1111	Platinum solder.....	Ag, 73; Pt, 27		1163	Reichs bronze.....	Cu, 85; Fe, 7.5; Al, 0.6; Mn, 0.5	
1112	Platinum substitute ( <i>v. also</i> Index Nos. 1046-1048, 1177)	Bi, 72; Al, 24; Bi, 3.7; Au, 0.7		1164	Reith's alloy.....	Cu, 74.5; Sn, 11.6; Pb, 9; Sb, 4.9	
	Platinum substitutes:			1165	Reostene.....	Ni; Fe	
1113	Cooper's.....	Ag, 70; Pd, 25; Co, 5		1166	Resistance.....	Cu, 57; Zn, 26; Ni, 18	480
1114	Cooper's.....	Ag, 70; Pt, 25; Ni, 5		1167	Resistance.....	Cu, 85; Mn, 12; Fe, 3	
1115	Electrical.....	Au, 70; Ag, 25; Ni or Pt, 5		1168	Resistance.....	Ag, 67; Pt, 33	474, 588
1116	Electrical.....	Au, 68; Ag, 25; Pt, 7.5		1169	Resistance, high, non-magnetic	Cr, 70; Ni, 30	
1117	Platnam.....	Ni, 54; Cu, 33; Sn, 13; Fe, 0.5; Al, 0.3		1170	Resistance, Lunge.....	Cu, 87-84; Mn, 12-14; Fe, 1.8-1.9 (for list of resistance alloys <i>v. p.</i> 391)	
1118	Platnik.....	Pt; Ni		1171	Resistin (resistance).....	Cu, 87-85; Mn, 12; Fe, 1.8-3	
1119	Plow steel.....	Fe; C, 0.6-0.9; S, 0.03; P, 0.02-0.03; Mn, 0.4-0.5; Si, 0.15-0.17	470, 491, 492, 516, 600, 602	1172	Rezistal.....	Fe; Ni, 22; Cr, 5.5; Si, 1.25; C, 0.15	
1120	Plumber's white, No. 1.....	Cu, 54; Zn, 27; Ni, 17; Pb, 2		1173	Rezistal (U. S. patents 1 420 707 and 1 420 708)	Fe; Ni, 36; Cr, 27.5; Si, 3.25; C, 0.7 ( <i>v. also</i> Index No. 179)	
1121	Plumber's white, No. 2.....	Cu, 54; Zn, 25; Ni, 13; Pb, 7; Sn, 1		1174	Rheotan.....	Cu, 84; Fe, 12; Zn, 4; Mn, 2	
1122	Plumber's white, No. 3.....	Cu, 58; Zn, 25; Ni, 15; Fe, 1; Pb, 1; Mn, 0.3		1175	Rheotan.....	Cu, 84; Mn, 12; Zn, 4	
1123	Plumbic bronze.....	Cu, 69; Pb, 26; Mn, 1.7; Sn, 1.5; Fe, 1.2		1176	Rheotan II.....	Cu, 53; Ni, 25; Zn, 18; Fe, 5	
1124	Ponsard's high Mn brass.....	Cu, 75-50; Mn, 20-25; Zn, 2-15; Fe, 0-16		1177	Rhotanium.....	Au, 90-60; Pd, 10-40	
1125	Popes Island metal*.....	Cu, 70; Zn, 15; Ni, 14; ? , 1	480	1178	Richards alloy.....	Zn, 96; Al, 4	465, 546
1126	Poro-bronze.....	Sn, 80; Sb, 13; Cu, 7	476	1179	Richards bronze.....	Cu, 55; Zn, 42-43; Fe, 1; Al, 2-1	556
1127	Poterie d'étain.....	Sn, 90; Sb, 9; Cu, 1	476	1180	Richardson's speculum.....	Cu, 65; Sn, 30; As, 2; Si, 2; Zn, 0.7	
1128	Potingris.....	Potinjaune plus Pb and Sn		1181	Rich gold metal.....	Cu, 90; Zn, 10	555
1129	Potinjaune (French yellow brass).....	Cu, 72; Zn, 25; Pb, 2; Sn, 1.2		1182	Rich low brass.....	Cu, 85; Zn, 15; Pb; Fe	555
1130	Pot metal.....	Cu, 80-67; Pb, 20-33	567	1183	Roberts-Austen (purple gold).....	Au, 79; Al, 21	
1131	Potosi silver.....	Nickel silver		1184	Rod brass.....	<i>v. Index Nos.</i> 603, 604	
1132	Presto steel (Carpenter).....	Fe; Cr, 1.4; C, 1.1		1185	Romanium.....	Al, 97; Ni, 1.8; Cu, 0.3; Sb, 0.3; W, 0.2; Sn, 0.2	
1133	Preuss' alloy.....	Fe; Co, 34; Si, 0.2-1.5; C, 0.04-0.06		1186	Roma bronze.....	Cu, 59; Zn, 41; Pb, 0.4; Al, 0.2; Fe	556
1134	Primer gilding.....	Cu, 97; Zn, 3; Pb; Fe	469, 555	1187	Ronia metal.....	Brass + Co; Mn; P	
1135	Princee's metal.....	Cu, 83-61; Zn, 17-39	555, 601	1188	Rosein.....	Ni, 40; Al, 30; Sn, 20; Ag, 10	
1136	Prince's metal.....	Sn, 85; Sb, 15	557	1189	Rosenhain and Arehbutt alloy (forging).....	Al, 72; Zn, 25; Cu, 3	537
1137	Projectile steel ( <i>v. also</i> Index No. 1142)	Fe; Cr, 2.4; C, 0.8; Mn, 0.4; Si, 0.2; P; S	507	1190	Rose's alloy.....	Bi, 50; Pb, 28; Sn, 22	
1138	Promethium.....	Cu, 67.5-67; Zn, 30; Al, 2.5-3	556	1191	Rose's alloy.....	Bi, 35; Pb, 35; Sn, 30	
1139	Propeller bushing.....	Zn, 69; Sn, 19; Sb, 7; Cu, 5		1192	Ross' alloy.....	Cu, 68; Sn, 32	555
1140	Propeller bushing.....	Bronze + Hg			Rotguss.....	<i>v. red bronze</i>	
1141	Proplatinum.....	Ni, 72; Ag, 24; Bi, 3.7; Au, 0.7		1193	Rotoxit.....	Cu; Si (non-corrosive)	
1142	Protective deck plate.....	Fe; Ni, 3.5; Cr, 1.5; C, 0.2-0.3	472, 512	1194	Rübel bronze (Rübel metal).....	Cu, 57-55; Zn, 39-40; Fe, 1.5-2; Ni, 1-3; Al, 0.5	556
1143	Protective (torpedo defense) netting.....	Fe; Ni, 27.8; C, 0.4	471, 482	1195	Rübel bronze.....	Cu, 39; Fe, 34; Ni, 18; Al, 8.4	
1144	Pyros.....	A heat resisting alloy		1196	Rübel bronze.....	Cu, 80; Al, 10; Fe, 4.5; Ni, 4.5; Mn, 1	
1145	Q-alloy (cast, grade K-1).....	Ni, 68; Cr, 20; Si, 2; Al, 1; (Fe, etc.), 10			Ruolz alloys (Ruolz silver).....	<i>v. Argent français</i>	
1146	Queen's metal.....	Sn, 73-51; Pb, 8.8-17; Sb, 9-17; Zn, 8.9-13			Rupert's metal.....	<i>v. Princee's metal</i>	
1147	Queen's metal.....	Sn, 89; Sb, 7; Cr, 3.5; Bi, 1		1197	Rustless sheets.....	Fe; Cu, >0.2; C	470, 509
1148	Queen's metal.....	Sn, 89-87; Sb, 7-8.5; Cu, 3.5; Zn, 1		1198	Rustless steel (Carpenter).....	Fe; Cr, 20; Cu, 1; C, 0.3	604, 606
	Rail steel (carbon) A. S. T. M. Spec. A1-24:			1199	Salge metal (antifriktion).....	Zn, 86; Sn, 9.9; Cu, 4; Pb, 1.1	
1149	Bessemer.....	C(0.37-0.55)†; Mn, 0.8-1.1; P, >0.1; Si, >0.2	470, 491, 516, 600	1200	Sallit's speculum.....	Cu, 65; Sn, 31; Ni, 4	
1150	Open hearth.....	C(0.5-0.75)†; Mn, 0.6-0.9; P, >0.04; Si, >0.2	470, 491, 492, 600	1201	Samlegierung.....	Fe; Mn, 13; Si, 10.2; Al, 5.8; C, 2.5; Cu, 0.3	
	Rail steel (manganese).....	<i>v. Index No.</i> 855		1202	Sceptre brass.....	Cu, 62; Zn, 36; Fe, 1.4; Al, 1.1; Pb, 0.07	556
1151	Rakel's metal.....	Cu, 88; Ni, 11; Mn, 1; Zn, 1		1203	Sehomberg alloy.....	Zn, 87; Sn, 10; Cu, 3	
1152	Randolf metal.....	A dental alloy		1204	Schomberg bearing.....	Zn, 59; Sn, 40; Cu, 0.4; Pb, 0.2; Fe, 0.2	476
1153	Raymur.....	Cu; Ni		1205	Schulz alloy.....	Zn, 91; Cu, 6; Al, 3	546
1154	Rayo.....	Ni, 85; Cr, 15	467, 480	1206	Scleron (Aeron).....	Al, 98-85; Cu; Ni; Zn; Li; Si; Mn	468, 534, 601, 608
1155	Reaetal.....	Ni; Cr		1207	Screw brass.....	Cu, 78; Zn, 16; Sn, 4.5; Pb, 1.5	
	Reamur.....	<i>v. Malleable east iron</i>		1208	Screw bronze.....	Cu, 94; Zn, 5; Sn, 1; Pb, 0.5	555
1156	Red brass ( <i>v. Tombac</i> ).....	Cu, 89-83; Zn, 5-12; Pb, 3-10; Sn, 2-5		1209	Screw-nut bronze.....	Cu, 86; Sn, 11; Zn, 2.3	565
1157	Red bronze (Rotguss).....	Cu, 93-82; Sn, 4-10; (Zn + Pb), 3-10	569	1210	Screw wire brass.....	Cu, 62; Zn, 38	555, 602
1158	Red gold.....	Au, 75; Cu, 25	586	1211	Sea water alloy.....	Fe; Ni, 17; Mn, 5; C, 0.7; Si	
1159	Red metal ( <i>v. also</i> Index No. 56)	Cu, 70; Zn, 20; Pb, 6; Sn, 4		1212	Sea water alloy.....	Fe; Ni, 24; Cr, 1.2; Mn, 0.6; C, 0.5; Si, 0.4; Co; Cu	512
1160	Red ray.....	Similar to Chromel B		1213	Sea water bronze.....	Cu, 45; Ni, 33; Sn, 16; Zn, 5.5; Bi, 1	
1161	Regel-metall.....	Sn, 83.3; Sb, 11.1; Cu, 5.6	557	1214	Seeretan.....	Cu, 95-91; Al, 9-5; Mg, 1.5; P, 0.5	

\* Generic name for a series of French alloys.

† Content increases with weight per unit length.



Index No.	Name	Composition	Page
1215	Selva metal.....	A high tensile brass	
1216	Semiplastic bronze.....	Cu, 79-75; Pb, 13.5-16.5; Sn, 7-9; P; Fe; Sb; Al	562, 567
1217	Semi steel.....	Fe; total C, 3.0-3.5; combined C, 0.5-0.81; Si, 1.4-1.8; Mn; P; S	464, 476, 497
1218	Shaku-do (Shakdo).....	Cu, 96-94; Au, 3.7-4.2; Ag, 1.6-0.1; Pb; Fe; As	
1219	Sheathing bronze.....	Cu, 45; Ni, 32.5; Sn, 16; Zn, 5.5; Bi, 1.5	
1220	Sheet brass.....	Cu, 72-55; Zn, 27-45; Pb, 0-2; Sn, 0-3.3; Fe	469, 556
1221	Sheet bronze.....	Cu, 100-90; Zn, 0-10	469, 555
1222	Sheffield (Ni silver).....	Cu, 63-55; Zn, 17-37; Ni, 11-19; Pb, 0-3	480, 601
1223	Sheffield, hard alloy.....	Cu, 46; Ni, 31; Zn, 20	475, 480
1224	Shell head brass.....	Cu, 75; Zn, 25	555, 601
1225	Shibu-ichi.....	Cu, 67-51; Ag, 32-49; Au; Fe	
1226	Ship nail alloy.....	Sn, 50; Pb, 33; Sb, 17	
1227	Ship nail brass.....	Cu, 64; Zn, 25; Pb, 8.5; Sn, 2.5	
1228	Sibley alloy.....	Al, 67; Zn, 33	468, 536
1229	Sibley casting alloy.....	Al, 80; Zn, 20	468, 536
1230	Sideraphite.....	Fe, 63; Ni, 23; Al, 5; Cu, 5; W, 4	
1231	Siemens Halske.....	Zn, 48; Cd, 47; Sb, 5	
1232	Silchrome.....	Fe, 64; Ni, 21; Cr, 6.2; Si, 6.1; Mn, 0.8; C, 0.14	
1233	Silchrome wire.....	Fe; Cr, 18; Si, 3; W, 3; C, 0.3	
1234	Silchrome.....	Fe; Cr, 3.2-8.3; Si, 3.5; C, 0.4	
1235	Silico-chromium steel.....	Fe; Cr, 9-12; Si, $\geq 5$ ; C, $\geq 1.2$	
1236	Silico-manganese brass.....	Cu; Zn, 40; Mn, 1-2; Fe, 0.2-0.3; Si, 0.05-1	556
1237	Silico-manganese steel.....	Fe; Mn, 0.45-15; Si, 0.4-1.9; C, 0.1-1.0; P; S	472, 525
1238	Silico-spiegel.....	Fe; Mn, 15-20; Si, 8-15; P, 0.15; S, 0.01; C	
1239	Silicon bronze.....	Cu, 98-91; Sn, 1.5-9; Si, 0.05	559
1240	Silicon-copper A. S. T. M. Spec. B53-24T	Cu; Si, 10-12; Fe, $\geq 0.75$ ; Al, Sn, Zn, each $\geq 0.25$ ; Cu + Fe + Si, $\leq 99.4$ (v. also Cuprosilicon)	464
1241	Silicon-ferro-chrome.....	Cr, 55-45; Fe, 30-50; Si, 1-17; C, 2.5-7	473
1242	Sillman bronze.....	Cu, 86.4; Al, 9.7; Fe, 3.9	578
1243	Silicon-nickel.....	Ni, 80-40; Si, 16-18; Fe, 2.5-30	473
1244	Silicon-manganese.....	Mn, 68; Si, 20; Fe, 11.6; C, 0.7	473
1245	Silicon-steel.....	Fe; Si, $\geq 6$ ; C, $\geq 0.25$ ; Mn; P; S (v. also p. 390)	472, 524, 525
1246	Silumin*.....	Al; Si, 5-14	543, 601
1247	Silvel.....	Cu, 73; Mn, 12; Sn, 12; Fe, 1.8; Pb, 0.5; Al, 0.3	
1248	Silvel.....	Cu, 68; Zn, 16; Mn, 6.8; Ni, 6.5; Fe, 2.2; Pb, 0.5; Al, 0.1	
1249	Silver (Rupée).....	Ag, 92; Cu, 8	584, 587
1250	Silver (U. S. coins).....	Ag, 90; Cu, 10	584, 587
1251	Silver bronze.....	Cu, 58; Zn, 23; Ni, 16; Pb, 2; Sn, 1	
1252	Silver bronze.....	Cu, 68; Mn, 18; Zn, 13; Al, 1.3; Si, 0.3	
1253	Silver bronze.....	Ag, 77; Cu, 23	464, 585
1254	Silver foil.....	Sn, 90; Zn, 10	
1255	Silver foil.....	Sn, 98; Cu, 2.5	561
1256	Silver foil.....	Sn, 91; Zn, 8.3; Pb, 0.4	
1257	Silverine.....	Cu, 80-71; Ni, 16-17; Zn, 1-8; Sn, 1-2.8; Co, 1-2; Fe, 1-1.5	
1258	Silverite.....	Nickel silver	
1259	Silver metal.....	Zn, 67; Ag, 33	
1260	Silveroid.....	Nickel silver	
	Silver solder:		
1261	Bureau of Standards.....	Ag, 40; Sn, 40; Cu, 14; Zn, 6	
1262	Common.....	Ag, 63; Cu, 30; Zn, 7.5	
1263	French.....	Ag, 66; Cu, 23; Zn, 10	
1264	Hard.....	Ag, 80; Cu, 13; Zn, 6.8	
1265	Medium.....	Ag, 75-70; Cu, 20-23; Zn, 5-7.5	

Index No.	Name	Composition	Page
1266	Pure silver.....	Ag, 72; Cu, 28	
1267	Quick.....	Ag, 63-57; Cu, 21-28; Zn, 10-12; Sn, 3.8-6.2	
1268	Sterling.....	Ag, 80; Zn, 18; Cu, 2.5	
1269	Similargent.....	Nickel silver	
1270	Similor.....	Cu, 89-80; Zn, 9-20; Sn, 0-7	555
1271	Sin-chu (Japanese brass).....	Cu, 66.5; Zn, 33.4; Fe, 0.1	469, 555
1272	S-less steel (Brearly).....	Fe; Cr, 13; C, 0.3	508, 603
1273	Smutter Lenian.....	Cu, 72; Ni, 13; Zn, 9.8; Sn, 2.3; Fe, 2; Bi, 1	
1274	S. M. L. alloy (Monel).....	Ni, 68; Cu, 28; Fe, 2.5; Mn, 1.5	469, 480, 604, 606
1275	S. M. steel (Carpenter).....	Fe; Si, 2; Mn, 0.8; C, 0.5-0.6	525, 604
1276	Soft gun metal (No. 11 alloy)	Cu, 90; Sn, 6.5; Zn, 2; Pb, 1.5	566
	Solder (A. S. T. M. Spec. B32-31):		
	Class A, Grade	Approx. Max. Max. Sn Pb Sb Cu	
1277	0.....	63 37 0.12 0.08	467, 557
1278	1.....	50 50 .12 .08	
1279	2.....	45 55 .12 .08	
1280	3.....	40 60 .12 .08	
1281	4.....	37.5 62.5 .12 .08	
1282	5.....	33 67 .12 .08	
	Class B, Grade		
1283	1.....	49.25 50 0.75 0.15	557
1284	2.....	43.5 55 1.5 .15	
1285	3.....	38 60 2 .15	
1286	4.....	35.5 62.5 2 .15	
1287	5.....	31 67 2 .15	
	All grades: Zn + Al = 0; other impurities, $\geq 0.1$		
1288	Solder, S. A. E. Specs. 1, 2, 3	Practically same as 1, 2, 3, above.	
1289			
1290			
1291	Solder, S. A. E. Spec. 4.....	Pb, 75; Sn, 24.5-25.5; Sb, $\geq 0.12$ ; Cu, $\geq 0.08$	467
	Class A.....	Zn + Al = 0; other impurities, $\geq 0.1$	
	Solder:		
	For B. E. S. A. Specifications	v. p. 386	
1292	Bismuth.....	Sn, 50-20; Pb, 25-40; Bi, 25-40	
1293	Brazing.....	Zn, 57-45; Cu, 35-45; Ni, 8-10	
1294	Half and half.....	Pb, 50; Sn, 50	467, 557
1295	Hard.....	Cu, 57-50; Zn, 43-50	470, 555
1296	Hard yellow.....	Cu, 53; Zn, 43; Sn, 1.3; Pb, 0.3	470, 555
1297	Plumber's.....	Pb, 67; Sn, 33	467, 557
1298	Readily fusible.....	Zn, 67; Cu, 33	465
1299	Refractory.....	Cu, 50; Zn, 50	465, 555
1300	Soft, nearly white.....	Zn, 50; Cu, 44; Sn, 3.3; Pb, 1.2	
1301	Tinman's.....	Sn, 67; Pb, 33	467, 557
1302	Very refractory.....	Cu, 58; Zn, 42	465, 555
1303	Very soft, white.....	Cu, 57; Zn, 28; Sn, 15	
1304	White.....	Zn, 60; Cu, 40	465
	Solders for various metals and alloys, v. under their names		
	Sondermessing.....	Special (alloy or high tensile) brass	
1305	Sorel's alloy.....	Zn, 80; Cu, 10; Fe, 10	
1307	Spandau alloy (Austrian alloy)	Zn; Cu, 4-6; Al, 2-3.5	546
1308	Speculum.....	Cu, 69-67; Sn, 31-33 (i.e., alloys of the approximate composition Cu <sub>3</sub> Sn and known by various names. For other speculum alloys, v. p. 391. Other intermetallic compounds as Mg <sub>3</sub> Al <sub>2</sub> are often suitable (v. equilibrium diagrams).	561
1309	Spark plug wire.....	Ni; Mn, 2-6; Fe; Cu	473, 482
1310	Spelter wire.....	Cu, 64; Zn, 36; Pb, 0.4; Fe, 0.2	555
1311	Spiauter (hard zinc).....	Zn, 90; Sb, 8; Cu, 2	
1312	Spiegeleisen (A. S. T. M. Spec. A98-25T):	Fe; Mn, 15-30; C, 5-6; Si, 1; P, 0.15; S, 0.05	

\* A German alloy similar to alpac.

Index No.	Name	Composition	Page	Index No.	Name	Composition	Page
1313	Grade A.....	Fe; Mn, 19-21; C, 6.5; P, 0.15; S, 0.04; Si; S*		1339	Soft (B)*.....	Fe; C, $\geq 0.15$ ; Mn, $\geq 0.7$ ; P, $\geq 0.115$	470, 487, 600, 602
1314	Grade B.....	Fe; Mn, 16-19; C, 6.5; P, 0.25; S, 0.05; Si; S*		1340	Soft (O. H.)*.....	Fe; C, 0.08-0.18; Mn, $\geq 0.55$ ; P, $\geq 0.05$ ; S, $\geq 0.06$	470, 487, 600, 602
1315	Spoon metal.....	Nickel silver		1341	Welding (B)*.....	Fe; C, $\geq 0.12$ ; Mn, $\geq 0.6$ ; P, $\geq 0.115$ ; S, $\geq 0.08$	470, 487, 600, 602
1316	Spring brass.....	Cu, 72-67; Zn, 28-33; Pb, Fe	555, 601			Other grades specified by points of carbon, thus: O. H. 25-40 carbon (1 point = 0.01 %)	
1317	Spring gold.....	Cu, 50; Au, 25; Ag, 25 (v. also Index Nos. 410, 1066)	586			For B. E. S. A. Specifications v. p. 386	
1319	Spring steel: A. S. T. M. Spec. Carbon, A14-16, grade A....	Fe; C, 0.9-1.1; Mn, $\geq 0.5$ ; P, $\geq 0.05$ ; S, $\geq 0.05$	470, 492, 602, 608	1342	Steel bronze.....	Cu; Al, 8.5; Pb, 1-2	
1320	Special carbon, A68-18.....	Same, but Si, 0.25-0.50	492, 493	1343	Steel bronze (Stahl bronze) name also applied to Uchatius bronze	Cu, 59-52; Zn, 36-43; Mn, 2.5-3; Fe, 1; Al, 1	556
1321	Cr-V, A60-16, grade A.....	Fe; Cr, 0.8-1.1; V, 0.15; C, 0.45-0.55; Mn, 0.5-0.8; P, $\geq 0.05$ † or 0.04;‡ S, $\geq 0.05$	472, 509, 603, 606	1344	Stellite.....	Co, 80-55; Cr, 20-35; W, 0-10	468, 593
1322	Si-Mn, A59-16, grade A.....	Fe; C, 0.45-0.55; Mn, 0.6-0.8; P, $\geq 0.05$ † or 0.045;‡ S, $\geq 0.045$ ; Si, 1.8-2.1	472, 523, 525, 604	1345	Stellite (No. 2).....	Co, 56; Cr, 34-40; W, 9.2; C, 1.5-2; Fe, 0-1	468, 593
	For B. E. S. A. Specifications	v. p. 386		1346	Stellite (No. 3).....	Co, 55; Cr, 20-23; W, 20-15; Fe, 5-3; C, 1.5-4	593
1323	Stainless iron.....	Fe; Cr, 12-14; Mn, 0.1; C, 0.1; Si; P; S	508, 603, 606	1347	Stellite.....	Co, 35; Cr, 26; W, 13; Fe, 10; Mo, 10; C, 1.8	593
1324	Stainless steel.....	Fe; Cr, 11-14; Mn, 0-0.5; C, 0.3-0.5; Si; P; S	471, 508, 600, 603	1348	Stellite.....	Co, 61-45; Mo, 24-40; Cr, 13-15; Fe	593
1325	Stalloy.....	Fe; Si, ca. 2.5; C		1349	Stellite.....	Co, 60-55; W, 25; Cr, 15; Mo, 0-5	
	Standard gold:			1350	Stephenson's alloy.....	Sn, 31; Fe, 31; Cu, 19; Zn, 19	
1326	Great Britain.....	Au, 92; Cu, 8	586, 589	1351	Stereotype metal.....	Pb, 82-70; Sb, 12-23; Sn, 3.2-17	
1327	U. S.....	Au, 90; Cu, 10	586, 590	1352	Stereotype metal.....	Sn, 60; Pb, 35; Sb, 5	
1328	Standard phosphor bronze "S" (Pa. R. R.)	Cu, 79.7; Sn, 10; Pb, 9.5; P, $\geq 0.8$	562	1353	Stereotype, standard (English)	Pb, 83; Sb, 13; Sn, 4.5	557
1329	Standard silver.....	Ag, 92.5; Cu, 7.5	584, 589	1354	Sterlin.....	Cu, 69; Ni, 18; Zn, 13; Pb, 0.8	480
1330	Standard (cadmium) silver....	Ag, 92.5; Cu, 5.75; Cd, 1.75	584	1355	Sterline.....	Cu, 68; Ni, 18; Zn, 13; Fe, 0.8	480
1331	Stanniol.....	Sn, 96; Pb, 2.4; Cu, 1; Ni, 0.3; Fe, 0.1		1356	Sterro metal.....	Cu, 60-55; Zn, 38-42; Fe, 1.8-4.7; Sn	556
1332	Statuary bronze.....	Cu, 95-88; Sn, 1.4-10; Zn, 0-9.5; Pb, 0-6; P; Ni	475, 476, 559-572	1357	Sterling metal.....	Cu, 66; Zn, 33-27; Fe, 0.7; Sn; Pb, 0-2	556
1333	Steam bronze.....	Cu, 88; Sn, 8.1; Pb, 2; Zn, 2	567	1358	Stone bronze.....	Cu, 58; Zn, 39; Fe, 1.5; Al, 0.8; Mn, 0.5; Sn	556
	Steel:	For a list of steels, v. p. 390		1359	Stone's English gear bronze	Cu, 89; Sn, 11; P	560, 601
	Automotive steels.....	v. pp. 372, 387		1360	Structural steel† (for bridges) A. S. T. M. A7-24	Fe; C; P, $\geq 0.06$ † or 0.04;‡ S, $\geq 0.05$ (tensile properties specified)	
1334	Billets, ingots, etc., of open hearth or electric steel for forging (A. S. T. M. Spec. A17-21)	Classified into types as follows: A: C steel B: Ni steel (Ni, $\geq 3$ ) C: Cr-Ni steel (Ni, 1-1.5; Cr, 0.45-0.75) D: Cr-Ni steel (Ni, 1.5-2; Cr, 0.9-1.25) E: Cr-Ni steel (Ni, 2.75-3.25; Cr, 0.6-0.95) F: Cr-Ni steel (Ni, $\geq 3$ ; Cr, $\geq 1$ ) G: Cr steel (Cr, 0.6-0.9) H: Cr-V steel (Cr, 0.8-1.1; V, 0.15) Specifications also limit impurities in each type Each type subdivided into grades according to carbon content For C steel; grade 1 = C, 0.05-0.15; grade 8 = C, 0.45-0.60 For alloy steels, same range is covered by grades 11 to 17.			For B. E. S. A. Specifications	v. p. 383	
1335	For B. E. S. A. Specifications Castings (A. S. T. M. Spec. A27-24) Grade A.....	C, $\geq 0.45$ ; P, $\geq 0.07$ † or 0.06‡	470, 487-491	1361	Structural nickel† steel A. S. T. M. A8-24	Fe; Ni, $\leq 3.25$ ; C, $\geq 0.45$ ; Mn, $\geq 0.7$ ; P, $\geq 0.05$ ; S, $\geq 0.05$	472, 481, 600, 602, 607
	Commercial bars (A. S. T. M. Spec. A80-24):			1362	Structural nickel† steel rivets, same spec.	Fe; Ni, $\leq 3.25$ ; C, $\geq 0.30$ ; Mn, $\geq 0.6$ ; P, $\geq 0.04$ † or 0.03;‡ S, $\geq 0.05$	
1336	Dead soft (O. H.)§.....	Fe; C, 0.05-0.12; Mn, $\geq 0.55$ ; P, $\geq 0.05$ ; S, $\geq 0.06$	470, 487, 488, 600	1363	Structural silicon steel, A. S. T. M. A94-25T	Fe; C, $\geq 0.40$ ; Si, $\leq 0.2$ ; P, $\geq 0.06$ † or 0.04;‡ S, $\geq 0.05$ (ladle analysis)	487-491, 523, 600, 602, 606
1337	Screw (B)§.....	Fe; C, 0.08-0.16; Mn, 0.6-0.8; P, 0.09-0.13; S, 0.075-0.15	470, 487, 488, 602	1364	Stuffing box alloy.....	Cu, 61.5; Ni, 15.5; Zn, 11; Pb, 10; Sn, 2	
1338	Screw (O. H.)§.....	Fe; C, 0.15-0.25; Mn, 0.6-0.9; P, $\geq 0.06$ ; S, 0.075-0.15	488, 489, 600, 602	1365	Suhler white copper.....	Cu, 40; Ni, 32; Zn, 25; Pb, 2.6	
				1366	Sun bronze.....	Co, 60-40; Cu, 30-50; Al, 10	574, 600
				1367	Sun bronze.....	Cu, 95; Al, 5	556
				1368	Superbronze.....	Cu, 57-69; Zn, 21-38; Mn, 3-3.2; Fe, 1.3-2; Al, 1.2-5	534
				1369	Susini.....	Al; Cu, 1.5-4.5; Mn, 1-8; Zn, 0.5-1.5	464, 542
				1370	T. metal.....	Al, 95; Mg, 3.8; Fe, 0.5; Si, 0.5; Cu, 0.1	
				1371	Talmi gold.....	Cu, 90; Zn, 8.9; Au, 0.9 (Au welded on by rolling)	556
				1372	Talmi gold.....	Cu, 86; Zn, 12; Sn, 1.1; Fe, 0.3	557
				1373	Tandem.....	Pb, 78; Sb, 17; Sn, 5.9	473
				1374	Tantiron.....	Fe, 83.5; Si, 15; C, 1	
					Tarnac.....	v. Manganin	
				1375	Taylor white.....	Fe; W, 8.5; Cr, 3; C, 0.75-1	
				1376	Tungsten steels.....	For list v. p. 390	

\* As specified.

† Acid.

‡ Basic.

§ B = Bessemer; O. H. = Open hearth.

\* B = Bessemer; O. H. = Open hearth.

† Must be open hearth.

‡ Acid.

§ Basic.



Index No.	Name	Composition	Page
1377	Telegraph bronze.....	Cu, 80; Pb, 7.5; Zn, 7.5; Sn, 5	561
1378	Tenax metal.....	Zn; Al, 4.2-4.6; Cu, 2.2-3; Pb, > 1.2; Fe, > 0.35	546
1379	Tensilite.....	Cu, 67-64; Zn, 24-29; Al, 3.1-4.4; Mn, 2.5-3.8; Fe, 0-1.2; Sn	556
1380	Terne metal.....	Pb, 88; Sn, 18; Sb, 1.8	
1381	Tetmajer Al bronze.....	Cu, 93-86; Al, 4.6-10; Si, 1-2.7; Fe, 0.7-1	
1382	Tberlo.....	Cu, 85; Mn, 13; Al, 2	
1383	Thermalloy.....	Fe, 72; Cr, 25; Mn, 2; Ni, 0.1; C, 0.1	
1384	Thermit (bearing).....	Pb; Sb, 15; Sn; Ni	
1385	Thorane.....	W; W <sub>2</sub> C	
1386	Three-twenty (3/20).....	Al, 77; Zn, 20; Cu, 3	538, 601
1387	Thurston's brass.....	Cu, 55; Zn, 44.5; Sn, 0.5	470, 556
1388	Tico.....	Fe, 67; Ni, 30; Mn, 1.1; Cu, 1.1	482
1389	Tiers argent.....	Al, 66; Ag, 33	
	Tin brass.....	For list v. p. 389	
1390	Tinfoil.....	Sn, 88; Pb, 8; Cu, 4; Sb, 0.5	
1391	Tinsel.....	Sn, 60; Pb, 40	
1392	Tissier's brass.....	Cu, 97; Zn, 2; As, 0-1; Sn, 0.5-0	
1393	Titan bronze.....	Cu, 56; Zn, 46; Fe, 0.3; Al, 0.2	556
1394	Titanium steel.....	Fe; Ti, 0.3-9; C, 0.1-0.8; Mn; Si; P; S	478
1395	Titan metal.....	v. Prometbium	
1396	Tobin bronze (American Brass Co.)	Cu, 60-59; Zn, 38-39; Sn, 2; Pb; Fe	556
1397	Tombac.....	Cu, 92-82; Zn, 8-18	469, 555
1398	Tombac (common).....	Cu, 72; Zn, 28	555, 600
1399	Tombac (French).....	Cu, 80; Zn, 17-20; Sn, 0-3	555, 556
1400	Tombac (red Vienna).....	Cu, 98; Zn, 2	469, 555
	Tool steel:		
	Carbon.....	v. High carbon steel	
1401	Highb speed.....	Fe; W, 12-14; Cr, 3-4; V, 1.5-2; C, 0.6-0.8 (v. also p. 390)	
1402	Tophet.....	Ni, 61; Fe, 26; Cr, 10; Mn, 3	480
1403	Torpedo bronze.....	Cu, 62-59; Zn, bal.; Sn, 0.5-1.5; Pb; Fe	470, 556, 602
1404	Toucas (Toncas?).....	Cu, 36; Ni, 29; Fe, Pb, Sn, Sb, Zn, each 7.1	
1405	Tournay's metal.....	Cu, 82.5; Zn, 17.5	469, 555
1406	Tourun Leonard's metal.....	Sn, 90; Cu, 10	561
1407	Trabuk metal.....	Sn, 88; Ni, 5.5; Sb, 5; Bi, 2	
1408	Trojan steel (Carpenter).....	Fe; Ni, 2; Cr, 1; C as desired	472, 510
1409	Tube brass.....	Cu, 70-60; Zn, 30-40; Pb; Fe	469, 555, 600, 602
1410	Tuc-Tur.....	Cu, 61-59; Zn, 21-29; Ni, 13-18; Fe, 0.3	475, 480
1411	Tula.....	Ag with a small amount of Cu and Pb	
1412	Tungsten brass.....	Cu, 60; Zn, 34; Al, 2.8; W, 2; Ni, 0.75; Mn, 0.7; Sn, 0.2	
1413	Tungsten brass.....	Cu, 60; Zn, 22; Ni, 14; W, 4	
1414	Tungsten filaments.....	W; TbO <sub>2</sub> , 0.5-0.75	462, 592
1415	Tungsten powder (A. S. T. M. Spec. A97-25T)	W, <95; maximum amounts of other elements; O, 1.0; Si, 0.75; C, 0.5; P, 0.05; S, 0.05; As; Bi; Cu; Sb; Sn, each 0.03	
1416	Tungsten steel.....	Fe; W, 1.7-2.2; C, 0.3-0.45; Mn; Si; P; S	472
1417	Turbadium bronze.....	Cu, 48; Zn, 46; Al, 2; Ni, 2; Mn, 1-8; Fe, 1; Sn, 0.5; Pb, 0.1	556
1418	Turbine brass.....	Cu, 76-67; Zn, 24-32; Pb; Fe	555, 601
1419	Turbine material.....	Cu, 81-79; Ni, 19-21; Fe, 0.8 max.	480, 601
1420	Turbiston's brass.....	Cu, 55; Zn, 41; Ni, 2; Al, 1; Fe, 0.8; Mn, 0.2	556
1421	Tutania (cast).....	Sn, 92; Sb, 4.7; Cu, 2.5; Pb, 0.3	557
1422	Tutania (cast, plate).....	Sn, 91-90; Pb, 8-6; Cu, 0.7-2.7; Zn, 0.3-1.3	557
1423	Tutania (English).....	Sn, 80; Sb, 16; Cu, 2.7; Zn, 1.3	

Index No.	Name	Composition	Page
1424	Tutenag.....	Commercial Zn, incorrectly applied to Paktong, i.e., Ni silver	
1425	Two to one.....	Cu, 66.7; Zn, 33.3	555, 602
1426	Type metal.....	Pb, 70; Sb, 18; Sn, 10; Cu, 2	
1427	(Common).....	Pb, 60-56; Sn, 10-40; Sb, 4.5-30	
1428	(English, French, German)...	Pb, 78-55; Sb, 5-30; Sn, 2-35; Cu, 0-1	
1429	(Standard).....	Pb, 58; Sn, 26; Sb, 15; Cu, 1	557
1430	Typewriter metal.....	Cu, 57; Ni, 20; Zn, 20; Al, 3	
1431	Uchatius (Uchatins?) bronze..	Cu, 92; Sn, 8	559, 601
1432	Udylite.....	Cd plating	
1433	Uleometal (Frary).....	Pb; (Ba + Ca), 1-2	556
1434	Uleony.....	Cu, 65; Pb, 35	567
1435	Ultra capital steel.....	Fe; W, 17; Cr, 3.4; V, 0.1; C, 0.7; Mn; Si; P; S	472
1436	Unmagnetizable watch wheels	Pt, 62.75; Ni, 18; Cu, 18; Cd, 1.25	
1437	Uranium steel.....	Fe; U, > 3; C, 0.2-0.7; Mn; Si; V	479
1438	U. S. N. brass.....	Cu, 80-78; Zn, 13-16; Sn, 4; Pb, 3; Fe	
	U. S. N. gun bronze.....	v. Index Nos. 652-654	
1439	U. S. N. valve bronze.....	Cu, 87; Sn, 7; Zn, 5; Pb, 1	567
1440	Va alloy.....	Al, 80; Zn, 14; Cu, 5; Fe, 0.7; V, 0.2	
1441	Valve bronze.....	Cu, 89-85; Sn, 2.5-10; Zn, 0-9; Pb, 0-6; P	563, 565
	Valve steel:		
1442	Brit. patent 131 492.....	Fe; Si, 5.8; Ti, 1.5; V, 1.5	
1443	Cbrome.....	Fe; Cr, 11-14; C, 0.4-1.2; Si, 0.1-0.2; S; P	470, 508, 603, 606
1444	Cbrome.....	Fe; Cr, 6.3; C, 0.5-1; Si, 0.1-0.3; Mn, 0-0.1; S; P	470, 508
1445	Tungsten.....	Fe; W, 14; Cr, 3; C, 0.6	472
1446	Very bard (Brit. patent 320 996)	W, 60; Fe, 26; Ti, 5; Cr, 4; C, 3; Ce, 2	
	For B. E. S. A. Specifications	v. p. 386	
1447	Vanadium brass.....	Cu, 70; Zn, 30; V, 0.5	
1448	Vanadium bronze.....	Cu, 61; Zn, 39; V, 0.5	
1449	Vanadium steel*.....	Fe; V, 0.1-14; C, 0.1-1.3; Mn; Si; P; S	472, 514, 604-607
1450	Vanadium.....	Al; V	
1451	Vaucher's alloy.....	Zn, 75; Sn, 18; Pb, 4.5; Sb, 2.5	
1452	Verilite.....	Al, 96; Ni, 1.5; Cr, 1.5; Cu, 1-0; Mn, 0.1	464
1453	Verilite.....	Al, 96; Cu, 2.5; Fe, 0.7; Si, 0.4; Mn, 0.3	533, 601
1454	Vestalin.....	Fe; Ni, 28; C	471, 482
1455	Victor bronze.....	Cu, 59; Zn, 39; Al, 1.5; Fe, 1.0; V, 0.03	556
	Victoria aluminium.....	v. Partinium	
1456	Victor metal.....	Cu, 50; Zn, 34; Ni, 15; Fe, 0.3; Al, 0.1	480
1457	Virginia silver.....	Nickel silver	
1458	VM steel (Crucible Steel Co. of America)	Fe; Cr, 0.7-1; Mo, 0.35-0.85; V, > 0.17; Mn, 0.4-0.6	472, 606
1459	Volomit.....	Similar to Stellite	
1460	Vulcan-bardite.....	Ni; etc. (v. also Index No. 679)	
1461	"W" Alloy.....	Al, 82; Cu, 12; Zn, 4.5; W, 1	
1462	W. 0.33.....	Al, 85; Cu, 14; Mn, 1	534
1463	Wagner's formula.....	Cu, 51; Zn, 19; Ni, 13	480
1464	Warne's metal.....	Sn, 37; Ni, 26; Bi, 26; Co, 11	
1465	Watch alloy.....	Cu, 50; Ni, 47.2; Cd, 2.8	
1466	Watch alloy.....	Au, 37.5; Cu, 27; Ag, 23; Pd, 12.5	
1467	Watch alloy.....	Pd, 70; Cu, 25; Ag, 4; Ni, 1	
1468	Watchmakers' alloy.....	Cu, 59; Zn, 40; Pb, 1.2	
1469	Wagner and Guhr's aluminum.	Sn, 80; Zn, 20	
1470	Welch's alloy (dental).....	Sn, 52; Ag, 48	585
1471	Wessel's silver.....	Cu, 66-51; Ni, 19-32; Zn, 12.5-17; Fe, 0-0.5; Ag, 0-2	480

\* Amount of V is usually under 0.4 %.

† C all in combined form.





B. S. S. No.	Description	Composition	Page
BRAZING SOLDER			
263	Grade A.....	Zn; Cu, 53-55; Pb, $\geq 0.3$ ; Fe, $\geq 0.15$ ; Bi, $\geq 0.05$ ; Sn, $\geq 0.05$ ; As, $\geq 0.05$ ; Sb, $\geq 0.05$ ; total impurities, $\geq 0.5$	470, 555
	Grade B.....	Zn; Cu, 49-51; impurities as in grade A above	465, 555

SILVER SOLDER			
206	Grade A.....	Ag, 60.0-62.0; Cu, 27.5-29.5; Zn, 9.0-11.0; impurities, $\geq 0.5$	
	Grade B.....	Ag, 42.0-44.0; Cu, 36.0-38.0; Zn, 18.5-20.5; impurities, $\geq 0.5$	

SOFT SOLDER*			
219	Grade A.....	Pb; Sn, 64.0-66.0; Sb, $\geq 1.0$ ; As, $\geq 0.05$ ; Fe, $\geq 0.02$	467, 557
	Grade B.....	Pb; Sn, 49.0-51.0; Sb, 2.5-3.0; As, $\geq 0.05$ ; Fe, $\geq 0.02$	557
	Grade C.....	Pb; Sn, 39.0-41.0; Sb, 2.0-2.4; As, $\geq 0.05$ ; Fe, $\geq 0.02$	
	Grade D.....	Pb; Sn, 29.0-31.0; Sb, 1.0-1.7; As, $\geq 0.05$ ; Fe, $\geq 0.02$	
	Grade E.....	Pb; Sn, 94.5-95.5; Sb, $\geq 0.50$	467
	Grade F.....	Pb; Sn, 49.0-51.0; Sb, $\geq 0.50$ ; As, $\geq 0.05$ ; Fe, $\geq 0.02$	467, 557
	Grade G.....	Pb; Sn, 41.0-43.0; Sb, $\geq 0.40$ ; As, $\geq 0.05$ ; Fe, $\geq 0.02$	467
	Grade H.....	Pb; Sn, 34.0-36.0; Sb, $\geq 0.30$ ; As, $\geq 0.05$ ; Fe, $\geq 0.02$	467, 557
	Grade J.....	Pb; Sn, 29.0-31.0; Sb, $\geq 0.30$ ; As, $\geq 0.05$ ; Fe, $\geq 0.02$	467

\* All grades contain: ZnO, 0; Al, 0; total impurities, including As and Fe,  $\geq 0.25$ .

GUNMETAL			
B 2	Gunmetal eastings	Cu, $\leq 86$ ; Sn, 10-12; Zn, $\geq 2.5$ ; Pb must be 0	476, 565

PHOSPHOR BRONZE			
B 8	Phosphor bronze eastings for bearings:†		
	For eastings....	Cu, 85-89; Sn, 10-13; P, 0.5-1.0	560
	For ingots for making eastings	Cu, 85-89; Sn, 10-13; P, 0.8-1.2	560

† Impurities in both classes are: Zn,  $\geq 0.25$ ; Pb,  $\geq 0.25$ ; total impurities,  $\geq 0.75$ ; P to be added in the form of P-Sn or P-Cu.

B. S. S. No.	Description	Composition	Page
AIRCRAFT STEELS†			
S 2		Fe	600
S 6		Fe; Mn, 0.40-0.80; C, 0.35-0.45	471, 491
S 11		Fe; Ni, 3.0-3.75; Cr, 0.50-1.00; Mn, 0.45-0.70; C, 0.25-0.35; W, $\geq 1.0$ ; Mo, $\geq 0.65$ ; V, $\geq 0.25$	472, 511, 604
S 14		Fe; Mn, 0.60-0.90; C, 0.10-0.18	471, 488
S 15		Fe; Ni, 2.75-3.5; Mn, 0.20-0.60; C, 0.10-0.15; Cr, $\geq 0.30$	472, 481, 603
S 28		Fe; Ni, 3.75-4.50; Cr, 1.00-1.50; Mn, 0.35-0.60; C, 0.25-0.32; W, $\geq 1.0$ ; Mo, $\geq 0.65$ ; V, $\geq 0.25$	472, 512, 604
S 61		Fe; Cr, $\leq 12.0$ ; Si, 0.50; Ni, $\geq 1.00$ ; C, $\geq 0.15$	471, 603
S 62		Fe; Cr, $\leq 12.0$ ; Si, 0.50; C, 0.15-0.35; Ni, $\geq 1.00$	471, 508
S 65		Fe; Ni, 2.75-3.5; Cr, 1.0-1.4; Mn, 0.35-0.65; C, 0.22-0.28; W, $\geq 1.0$ ; Mo, $\geq 0.65$ ; V, $\geq 0.25$	472, 508, 604
S 67		Fe; Ni, 4.6-5.2; C, 0.08-0.14; Mn, $\geq 0.35$ ; Cr, $\geq 0.1$	481, 604
S 68		Fe; W, $\leq 14.0$ ; Cr, $\leq 3.5$ ; C, 0.55-0.70; Mn, $\geq 0.40$	472
S 69		Fe; Ni, 3.25-3.75; Mn, 0.50-0.80; C, 0.35-0.45; Cr, 0.30	472, 481
S 70		Fe; C, 0.50-0.60; Mn, 0.40-0.75	470, 491
S 71		Fe; Mn, 0.40-0.80; C, 0.25-0.35	471, 489
S 76		Fe; Mn, 0.50-0.80; C, 0.30-0.45; Ni, $\geq 1.0$ ; Cr, $\geq 0.5$	471, 489-491

† All steels except S 61, S 62 and S 68 contain Si, 0.30; S, 0.05; P, 0.05.

AUTOMOTIVE STEELS			
5005/101	Wrought steels for forging	Fe; Mn, 0.40-1.00; Si, $\geq 0.30$ ; C, $\geq 0.20$ ; S, $\geq 0.07$ ; P, $\geq 0.07$	471, 488, 602
5005/102		Fe; Ni, 1.50-2.25; Mn, $\geq 0.60$ ; Cr, $\geq 0.30$ ; Si, $\geq 0.30$ ; C, $\geq 0.15$ ; S, $\geq 0.05$ ; P, $\geq 0.05$	480, 481
5005/103		Fe; Ni, 2.50-3.5; Mn, 0.20-0.60; Cr, $\geq 0.30$ ; Si, $\geq 0.30$ ; C, $\geq 0.15$ ; S, $\geq 0.05$ ; P, $\geq 0.05$	472, 480, 481, 603
5005/104		Fe; Ni, 4.50-6.0; Mn, $\geq 0.40$ ; Cr, $\geq 0.30$ ; Si, $\geq 0.30$ ; C, $\geq 0.15$ ; S, $\geq 0.05$ ; P, $\geq 0.05$	471, 481, 604
5005/201		Fe; Mn, 0.40-0.80; C, 0.15-0.25; Si, $\geq 0.30$ ; S, $\geq 0.06$ ; P, $\geq 0.06$	488, 489, 602
5005/202		Fe; Mn, 0.40-0.80; C, 0.25-0.35; Si, $\geq 0.30$ ; S, $\geq 0.06$ ; P, $\geq 0.06$	489-491, 602

No. B. S. S.	Description	Composition	Page
AUTOMOTIVE STEELS.—(Continued)			
5005/203		Fe; Mn, 0.40–0.80; C, 0.35–0.45; Ni, $\geq 1.0$ ; Si, $\geq 0.30$ ; S, $\geq 0.06$ ; P, $\geq 0.06$	471, 491, 600, 602
5005/204		Fe; Mn, 0.40–0.80; Ni, 0.30–1.0; C, 0.35–0.45; Si, $\geq 0.30$ ; S, $\geq 0.06$ ; P, $\geq 0.06$	481
5005/301		Fe; S, $\geq 0.05$ ; P, $\geq 0.05$	
5005/302		Fe; S, $\geq 0.05$ ; P, $\geq 0.05$	
5005/401		Fe; Ni, 2.75–3.50; Mn, 0.35–0.75; C, 0.25–0.35; Cr, $\geq 0.30$ ; Si, $\geq 0.30$ ; S, $\geq 0.05$ ; P, $\geq 0.05$	472, 481, 600, 603
5005/402		Fe; Ni, 3.25–3.75; Mn, 0.50–0.80; C, 0.35–0.45; Cr, $\geq 0.30$ ; Si, $\geq 0.30$ ; S, $\geq 0.05$ ; P, $\geq 0.05$	472, 481, 600, 603
5005/501		Fe; Ni, 3.00–3.75; Cr, 0.50–1.00; Mn, 0.45–0.70; C, 0.28–0.34; Si, $\geq 0.30$ ; S, $\geq 0.05$ ; P, $\geq 0.05$	472, 511, 512, 604
5005/502		Fe; Ni, 3.75–4.75; Cr, 1.00–1.50; Mn, 0.35–0.60; C, 0.25–0.35; Si, $\geq 0.30$ ; S, $\geq 0.05$ ; P, $\geq 0.05$	472, 512, 600, 604
5005/503		Fe; Ni, 1.25–1.75; Cr, 0.75–1.25; Mn, 0.45–0.65; C, 0.35–0.42; Si, $\geq 0.30$ ; S, $\geq 0.05$ ; P, $\geq 0.05$	472, 510, 600, 604
5005/601		Fe; Cr, 1.00–1.50; Mn, 0.50–0.80; C, 0.35–0.45; Si, $\geq 0.30$ ; V, $\geq 0.25$ ; S, $\geq 0.05$ ; P, $\geq 0.05$	472, 509, 600, 603
5028	Castings: Grade 1.....	Fe; Mn, $\leq 0.4$ ; S, 0.06; P, 0.05; C, $\geq 0.30$	487–490
	Grade 2	Fe; Mn, $\leq 0.6$ ; S, 0.08; P, 0.07	
5006/105	For cold working: Bars and strip... Wire.....	Fe; Mn, 0.40–0.80; Si, 0.30; C, 0.15–0.20; S, 0.04–0.06; P, 0.04–0.06	488, 489
5006/205–9			
5006/210		Fe; Mn, 0.5–0.9; C, 0.40–0.60; Si, $\geq 0.20$ ; S, $\geq 0.05$ ; P, $\geq 0.05$	491

SPRING STEELS§			
5010/218	Laminated springs	Fe; Mn, 0.60–1.0; C, 0.50–0.65; Si, $\geq 0.50$	491, 602
5010/219		Fe; C, 0.75–0.90; Mn, 0.35–0.70; Si, $\geq 0.40$	492, 602
5010/603		Fe; C, 0.55–0.65; Mn, 0.50–0.80; Cr, 0.45–0.70; Si, $\geq 0.50$	506
5010/604		Fe; Cr, 1.00–1.40; Mn, 0.50–0.80; C, 0.45–0.55; Si, $\geq 0.50$	506, 605
5010/605		Fe; Cr, 0.80–1.20; Mn, 0.50–0.80; C, 0.45–0.55; V, $\leq 0.15$ ; Si, $\geq 0.50$	509, 605
5010/801		Fe; Si, 1.50–2.0; Mn, 0.60–1.00; C, 0.50–0.60	523, 604

§ All these steels contain: S,  $\geq 0.05$ ; P,  $\geq 0.05$ .

B. S. S. No.	Description	Composition	Page
STRUCTURAL STEEL FOR BRIDGES			
15		Fe; P, $\geq 0.08$ ; S, $\geq 0.06$	
VALVE STEELS			
114/K10		Fe; Ni, 2.75–3.50; Mn, 0.35–0.75; C, 0.25–0.35; Cr, $\geq 0.3$ ; Si, $\geq 0.30$ ; S, $\geq 0.05$ ; P, $\geq 0.05$	481, 600, 603
114/S19		Fe; Cr, 8.0–12.0; C, 0.40–0.70; Si, 0.30–0.60; Ni, $\geq 1.00$	508, 600, 603
5008/403		Fe; Ni, 2.75–3.50; Mn, 0.35–0.75; C, 0.25–0.35; Cr, $\geq 0.30$ ; Si, $\geq 0.30$ ; S, $\geq 0.05$ ; P, $\geq 0.05$	472, 481, 600, 603
5008/602		Fe; Cr, 10.0–14.0; Mn, 0.30–0.60; C, 0.30–0.50; Ni, $\geq 1.00$	471, 508, 603
5008/603		Fe; Cr, 6.5–8.5; C, 0.50–0.70; Mn, 0.30–0.60; Ni, $\geq 1.00$	470, 508
5008/701		Fe; W, $\leq 14.0$ ; Cr, $\leq 3.5$ ; C, 0.55–0.70; Mn, $\geq 0.40$	472
ZINC ALLOYS			
220	Fine zinc (or spelter): Grade A.....	Zn, $\leq 99.95$ ; Cd, $\geq 0.02$ ; Pb, $\geq 0.02$ ; Fe, $\geq 0.01$ ; As, 0; Sb, 0; Al, 0; Sn, 0	462, 545, 546
	Grade B.....	Zn, $\leq 99.90$ ; Pb, $\geq 0.08$ ; Cd, $\geq 0.03$ ; Fe, $\geq 0.01$ ; As, 0; Sb, 0; Al, 0; Sn, 0	
221	Special zinc (or spelter)	Zn, $\leq 99.50$ ; Cd, $\geq 0.25$ ; Pb, $\geq 0.20$ ; Fe, $\geq 0.05$ ; As + Sb, $\geq 0.02$ ; Al, 0; Sn, 0	
222	Foundry zinc (or spelter)	Zn, $\leq 98.50$ ; Pb, $\geq 1.25$ ; Cd, $\geq 0.25$ ; Fe, $\geq 0.07$ ; Sn, $\geq 0.02$ ; As + Sb, $\geq 0.02$ ; Al, 0	

#### TABLES OF ALLOY CLASSES

In these tables most of the alloys listed in the finding index above, are classified according to composition and according to some of their more important uses. If the alloy class contains many alloys it is broken up into sub-classes according to the type formulae of the alloys comprised in it. Thus the class "Cast Light Alloys" is divided into the sub-classes: Al-Cu; Al-Mg; etc., each containing alloys, the first two symbols of whose type formulae are the same.

In these tables the alloys are identified by their index numbers in the finding index.

#### Light Alloys

(Al- or Mg-base alloys)

#### CAST LIGHT ALLOYS

Al-Ag: 149, 1389; Al-Cr: 361; Al-Cu: 13, 24, 28, 43, 44, 46, 47, 66, 73, 74, 76, 87, 88, 89, 91, 92, 94, 95, 96, 98, 99, 100, 110, 163, 199, 432, 473, 594, 595, 711, 755, 764, 765, 766, 774, 809, 810, 811, 813, 814, 815, 823, 826, 827, 833, 840, 874, 882, 885, 945, 983, 1063, 1064, 1206, 1453, 1461, 1462, 1490, 1491; Al-Mg: 27, 819, 820, 824,



825, 1370, 1500; **Al-Mn**: 72, 254; **Al-Ni**: 57, 58, 265, 1185, 1452; **Al-Sb**: 1062, 1487; **Al-Si**: 37, 60, 61, 68, 69, 70, 93, 101, 1246; **Al-Sn**: 797, 828, 860, 875, 905; **Al-V**: 1450; **Al-Zn**: 25, 48, 49, 63, 65, 67, 75, 90, 97, 112, 131, 132, 513, 674, 763, 791, 876, 877, 878, 879, 891, 920, 921, 1228, 1229, 1440, 1501, 1509, **Mg-Al**: 490, 491, 492, 493, 494, 495, 528, 529, 923; **Mg-Cu**: 496; **Mg-Zn**: 530.

#### WROUGHT LIGHT ALLOYS

**Al-Ag**: 150; **Al-Cu**: 14, 23, 40, 44, 78, 79, 81, 82, 83, 84, 85, 110, 137, 508, 510, 712, 751, 774, 812, 833, 883, 884, 911, 925, 1369, 1499; **Al-Mg**: 26, 509, 824, 829, 1507; **Al-Mn**: 77, 682; **Al-Ni**: 57, 1016; **Al-Si**: 62, 86, 1039, 1497; **Al-Zn**: 1, 50, 80, 184, 520, 611, 873, 1189, 1386, 1496, 1498, 1506, 1507; **Mg-Al**: 528, 529, 923; **Mg-Zn**: 530.

#### Copper Alloys

##### SIMPLE BRASSES

Type formula: Cu-Zn

**Zn, 1-10 %**: 195, 268, 321, 333, 340, 401, 620, 683, 738, 861, 1069, 1087, 1134, 1181, 1221, 1270, 1371, 1392, 1397, 1400; **Zn, 11-20 %**: 169, 193, 318, 600, 651, 669, 683, 738, 799, 861, 888, 1030, 1087, 1182, 1270, 1397, 1399, 1405; **Zn, 21-30 %**: 259, 278, 301, 308, 380, 439, 455, 517, 651, 693, 734, 773, 1220, 1224, 1316, 1398, 1418, 1486, 1493; **Zn, 31-40 %**: 282, 308, 323, 339, 380, 398, 400, 403, 464, 487, 497, 651, 773, 913, 918, 919, 1088, 1135, 1210, 1220, 1271, 1316, 1409, 1418, 1425, 1486, 1493; **Zn, 41-50 %**: 194, 282, 599, 821, 919, 1220, 1295, 1299, 1302.

##### LEADED BRASSES

Type formula: Cu-Zn-Pb

**Zn, 1-10 %**: 306, 379, 603, 683, 778; **Zn, 11-20 %**: 651, 683, 777, 780; **Zn, 21-30 %**: 651, 772, 773, 777, 782, 938, 1022, 1220, 1493; **Zn, 31-40 %**: 322, 377, 378, 395, 604, 651, 677, 683, 706, 773, 777, 868, 919, 1220, 1310, 1468, 1493; **Zn, 40-50 %**: 919, 1220.

#### TIN BRASSES, INCLUDING NAVAL BRASS

Type formula: Cu-Zn-Sn

**Sn, <4 %**: **Zn, 1-10 %**: 489, 593, 683, 738, 861, 1091, 1270, 1392; **Zn, 11-20 %**: 2, 324, 527, 600, 665, 683, 738, 818, 861, 1030, 1067, 1270, 1372, 1399; **Zn, 21-30 %**: 16, 622, 773, 1220, 1303, 1493; **Zn, 31-40 %**: 17, 253, 323, 622, 773, 926, 927, 1031, 1220, 1396, 1403, 1493; **Zn, 41-50 %**: 1021, 1220, 1387.

**Sn, >4 %**: **Zn, 1-10 %**: 861, 1270; **Zn, 11-20 %**: 209, 667, 861, 1024, 1030, 1270; **Zn, 21-30 %**: 209, 1032.

##### LEADED TIN BRASSES

Type Formula: Cu-Zn-Sn-Pb

**Sn, <4 %**: **Zn, 1-10 %**: 297, 683, 704, 1092, 1156, 1208, 1492; **Zn, 11-20 %**: 298, 402, 457, 683, 1156, 1159, 1207; **Zn, 21-30 %**: 267, 540, 542, 622, 773, 1128, 1129, 1220, 1227, 1493; **Zn, 31-40 %**: 299, 300, 622, 733, 773, 1077, 1078, 1220, 1493; **Zn, 41-50 %**: 1220, 1296.

**Sn, >4 %**: **Zn, 1-10 %**: 295, 296, 666, 1156; **Zn, 11-20 %**: 1156, 1159, 1207, 1438; **Zn, 21-30 %**: 210, 399, 1493; **Zn, 31-40 %**: 1493.

#### HIGH TENSILE BRASSES (EXCLUDING MANGANESE BRONZES)

Type formulae: Cu-Zn-Al; Cu-Zn-Fe; etc.

30, 102, 264, 468, 511, 512, 538, 614, 685, 686, 695, 705, 966, 979, 1020, 1138, 1179, 1186, 1187, 1194, 1202, 1215, 1236, 1356, 1357, 1358, 1368, 1379, 1393, 1395, 1412, 1417, 1420, 1447, 1448, 1455, 1484.

#### MANGANESE BRASSES (SO-CALLED MANGANESE BRONZES)

**Low manganese** (type formula: Cu-Zn-Mn): 465, 599, 721, 842, 844, 845, 852, 979, 1059, 1187, 1343, 1368, 1379. **High manganese** (type formula: Cu-Mn-Zn): 430, 842, 846, 852, 1124, 1248, 1252.

#### TIN (ORDINARY) BRONZES

Type formula: Cu-Sn

**Sn, 1-10 %**: 142, 526, 592, 612, 664, 750, 770, 843, 887, 1034, 1332, 1431; **Sn, 11-20 %**: 203, 257, 258, 612, 664, 843, 1359; **Sn, 21-30 %**: 255, 257, 767; **Sn, 31-40 %**: 543, 916, 1037, 1192, 1308.

##### PHOSPHOR BRONZES

Type formula: Cu-Sn-P

**Sn, 1-10 %**: 319, 345, 419, 535, 612, 681, 775, 932, 1081, 1082, 1083, 1332, 1441; **Sn, 11-20 %**: 204, 217, 218, 302, 303, 350, 612, 775.

##### ZINC BRONZES

Type formula: Cu-Sn-Zn-(P)

**Sn, 1-10 %**: 18, 129, 205, 206, 305, 394, 472, 612, 652, 664, 694, 731, 771, 843, 887, 931, 933, 1033, 1332, 1441. **Sn, 11-20 %**: 8, 205, 257, 521, 612, 664, 726, 747, 768, 843, 929, 1012, 1209. **Sn, 21-30 %**: 256, 257. **Sn, 31-40 %**: 256.

##### LEADED ZINC BRONZES

Type formula: Cu-Sn-Zn-Pb

**Sn, 1-10 %**: 19, 207, 294, 295, 612, 654, 664, 725, 779, 843, 936, 1157, 1276, 1332, 1333, 1439, 1441. **Sn, 11-20 %**: 207, 208, 257, 589, 612, 653, 664, 714, 767, 843. **Sn, 21-30 %**: 257, 589. **Sn, 31-40 %**: 589. **Sn, 41-50 %**: 881.

##### LEAD BRONZES

Type formula: Cu-Sn-Pb-(Zn), Pb < 15 %

**Sn, 1-10 %**: 5, 172, 211, 212, 271, 304, 500, 541, 664, 843, 1157, 1328, 1441; **Sn, 11-20 %**: 134, 202, 257, 589, 664, 761, 843, 930; **Sn, 21-30 %**: 257, 589; **Sn, 31-40 %**: 589.

Type formula: Cu-Pb-Sn-(Zn), Sn < 15 %

**Pb, 1-10 %**: 201, 212, 213, 355, 664, 802, 912, 1038, 1332, 1377, 1441; **Pb, 11-20 %**: 6, 35, 55, 201, 214, 215, 331, 335, 458, 459, 519, 553, 556, 801, 1216; **Pb, 21-30 %**: 29, 34, 35, 55, 216, 456, 745, 1123; **Pb, 31-40 %**: 55, 342, 469.

##### SPECIAL BRONZES

Type formula: Cu-Sn-X

148, 270, 337, 514, 615, 694, 732, 1080, 1238.

##### ALUMINUM BRONZES

**Cu-Al**: 103, 453, 488, 1026, 1027, 1028, 1029, 1070, 1367; **Cu-Al-Au**: 650, 1018; **Cu-Al-Fe**: 45, 104, 130, 141, 570, 934, 1242; **Cu-Al-Mg**: 105, 1214; **Cu-Al-Mn**: 106, 1070; **Cu-Al-Ni**: 109, 317, 488; **Cu-Al-Ni-Fe**: 606, 1196; **Cu-Al-Pb**: 1070, 1342; **Cu-Al-Si**: 471, 1381.

##### Nickel Silvers

Type formulae, Cu-Ni-Zn and Cu-Zn-Ni

**Generic names**: 51, 166, 167, 168, 354, 834, 939, 940, 1125, 1131, 1258, 1260, 1269, 1315, 1457.

**Ni, 1-10 %:** 263, 431, 531, 608, 966, 981, 982, 985, 1476; **Ni, 11-20 %:** 151, 154, 156, 158, 165, 263, 336, 396, 531, 605, 608, 617, 618, 619, 834, 853, 966, 978, 986, 987, 988, 989, 992, 993, 994, 995, 1025, 1166, 1222, 1410, 1456, 1463, 1478, 1483; **Ni, 21-30 %:** 135, 165, 262, 263, 533, 608, 616, 618, 978, 990, 991, 1101; **Ni, 31-40 %:** 978, 1045, 1223; **Ni, 41-50 %:** 1045.

#### SPECIAL NICKEL SILVERS

Nickel silver plus additional elements: this class is divided into sub-classes according to added elements

**Ag:** 59, 1471; **Al:** 111, 1430; **Al-Cr:** 363; **Cd:** 147, 1054; **Co-Ag:** 356; **Cr:** 1056; **Fe:** 152, 153, 155, 157, 175, 176, 177, 178, 839, 1045, 1176, 1355, 1473; **Fe-Pb:** 1122, 1404; **Fe-Si:** 623; **Fe-Sn-Co:** 808, 1055; **Mn:** 136, 138, 852, 859, 1248; **Mn-Sn:** 853, 979; **Pb:** 39, 993, 995, 1120, 1222, 1354, 1365; **Pb-Sn:** 139, 164, 165, 484, 968, 977, 992, 1121, 1251, 1364; **Sb-Co-Fe:** 1090; **Sn-Bi:** 274, 275, 276, 937, 968; **Sn-Co:** 198, 382, 1257; **Sn-Fe-Bi:** 1273; **W:** 1100, 1413.

#### Lead Base Alloys

**As:** 785; **Ba:** 602, 807; **Ca:** 186, 332, 390, 867, 1433; **Cd:** 124; **Cu:** 50, 421; **Fe:** 783; **Mg:** 676; **Na:** 1011; **Sb:** 144, 145, 196, 219-221, 225-232, 460, 475, 525, 532, 624, 627, 629, 657, 658, 659, 710, 715, 735, 757, 786, 794, 795, 822, 831, 910, 1014, 1017, 1065, 1351, 1353, 1373, 1384, 1426, 1427, 1428, 1482; **Sn:** 3, 7, 222, 223, 224, 233, 334, 386, 557, 609, 784, 862, 924, 928, 1040, 1041, 1278-1287, 1291, 1294, 1297, 1380, 1427, 1428, 1429.

#### Tin Base Alloys

**Al:** 113, 293; **Bi:** 387, 1485; **Cu:** 498, 560, 621, 675, 692, 740, 1076, 1094, 1255, 1406; **Fe:** 1350; **Ni:** 1407, 1464; **P:** 1085; **Pb:** 235, 247, 248, 388, 476, 477, 539, 550, 559, 709, 869, 1045, 1075, 1146, 1226, 1277, 1278, 1292, 1294, 1301, 1331, 1352, 1390, 1391, 1422, 1481; **Sb:** 20, 53, 162, 174, 185, 236, 237, 238, 240, 241, 242, 243, 244, 245, 246, 310, 311, 312, 313, 314, 315, 404, 474, 485, 678, 713, 736, 739, 741, 776, 894, 935, 1042, 1043, 1060, 1126, 1127, 1136, 1147, 1148, 1161, 1421, 1423; **Zn:** 41, 114, 115, 116, 120, 121, 122, 123, 239, 279, 673, 1061, 1254, 1256, 1469, 1475.

#### Zinc Base Alloys

**Ag:** 1259; **Al:** 118, 125, 126, 480, 746, 1178, 1378, 1495, 1510; **Cd:** 117, 1231; **Cu:** 41, 159, 249, 269, 272, 482, 483, 523, 597, 598, 672, 793, 806, 838, 1086, 1096, 1108, 1205, 1293, 1298, 1300, 1304, 1305, 1306, 1307, 1474; **Fe:** 684; **Pb:** 749; **Sb:** 505, 625, 788, 1311; **Sn:** 119, 197, 250, 251, 309, 478, 479, 481, 506, 524, 563, 628, 691, 789, 1044, 1139, 1199, 1203, 1204, 1451, 1505.

#### Alloys Containing the Precious Metals

##### SILVER ALLOYS

**Ag, < 20 %:** 149, 288, 534, 630-636, 638-641, 643, 660, 662, 874, 875, 877, 879, 904, 1049, 1053, 1066, 1188, 1467, 1471; **Ag, 20-30 %:** 160, 161, 410, 534, 634, 636, 637, 640, 646, 660, 914, 1105, 1116, 1141, 1317, 1466, 1494; **Ag, 31-40 %:** 161, 411, 534, 640, 642, 644, 645, 647, 1051, 1225, 1259, 1261, 1389; **Ag, 41-50 %:** 534, 1225, 1470; **Ag, 51-60 %:** 648, 1103, 1267; **Ag, 61-70 %:** 1097, 1103, 1110, 1113, 1114, 1168, 1262, 1263, 1267; **Ag, 71-80 %:** 1097, 1103, 1111, 1253, 1264, 1265, 1266, 1268; **Ag, 81-90 %:** 351, 1097, 1250, 1329; **Ag, 91-100 %:** 1249, 1330, 1411.

##### GOLD ALLOYS

**Au, < 20 %:** 648, 650, 1018, 1105, 1112, 1141, 1218; **Au, 21-30 %:** 410, 660, 1317; **Au, 31-40 %:** 639, 645, 1053, 1466; **Au, 41-50 %:**

462, 638, 642, 643, 644; **Au, 51-60 %:** 534, 636, 637, 647, 1106, 1494; **Au, 61-70 %:** 534, 634, 635, 640, 646, 1066, 1104, 1115, 1116, 1177; **Au, 71-80 %:** 281, 534, 633, 640, 641, 660, 1046, 1158, 1177, 1183, 1480; **Au, 81-90 %:** 534, 632, 662, 1052, 1177, 1327, 1479, 1480; **Au, 91-100 %:** 630, 631, 1049, 1326.

#### ALLOYS CONTAINING METALS OF THE PLATINUM GROUP

**Pt, < 20 %:** 351, 408, 409, 904, 1035, 1102, 1103, 1116; **Pt, 20-30 %:** 408, 903, 1047, 1097, 1103, 1104, 1111, 1114; **Pt, 31-40 %:** 1097, 1106, 1110, 1168; **Pt, 41-50 %:** 411; **Pt, 51-60 %:** 1098, 1105; **Pt, 91-100 %:** 1107, 1109.

**Pd, < 20 %:** 1047, 1052, 1177, 1466, 1479; **Pd, 20-30 %:** 1046, 1113, 1177; **Pd, 31-40 %:** 1177; **Pd, 61-70 %:** 1051, 1436, 1467; **Pd, 81-90 %:** 1050, 1107, 1109.

**Ir:** 1035, 1036, 1098, 1107.

**Rh:** 1035, 1036, 1109.

**Os:** 1035, 1036.

**Ru:** 1035, 1036.

#### Irons

##### CAST IRONS AND PIG IRONS

4, 191, 192, 349, 353, 441, 536, 579, 601, 656, 661, 835-837, 1071, 1217, 1477.

##### HIGH SILICON CAST IRONS

52, 423, 515, 516, 730, 1374.

##### ALLOY CAST IRONS

870, 871, 974.

##### RECARBURIZERS AND STEEL MILL ALLOYS

337, 565-569, 571-574, 576-585, 1238, 1239, 1241, 1244, 1312-1314.

##### COMMERCIALLY PURE, INGOT AND WROUGHT IRONS

170, 346, 724, 729, 1489.

#### Steels

##### CARBON STEELS

341, 347, 437, 558, 607, 670, 698, 737, 800, 866, 889, 898, 1019, 1119, 1149, 1150, 1319, 1320, 1334-1341, 1360.

##### ALLOY STEELS

##### Classified by alloying elements

**Al:** 127, 128; **B:** 292; **Ce:** 344; **Co:** 393, 1074, 1133; **Co-W-Cr:** 760; **Cr:** 12, 376, 422, 596, 1132, 1137, 1272, 1323, 1324, 1443, 1444; **Cr-Co:** 502, 690; **Cr-Cu:** 1198; **Cr-Mo:** 360, 371, 805, 900, 901, 902, 915; **Cr-Ni:** 329, 591, 758, 759; **Cr-Si:** 171, 466, 467, 941, 1235; **Cr-Si-W:** 1233; **Cr-U:** 374; **Cr-V:** 375, 1321; **Cu:** 418, 1197; **Mn:** 854, 855, 1019; **Mn-Si:** 1236; **Mo:** 906; **Mo-Co-Cr:** 700; **Mo-Co-V:** 703; **Mo-Cr:** 702; **Mo-Cr-Co-U:** 701; **Mo-V:** 1458; **Ni:** 586, 727, 756, 892, 996-1001, 1099, 1143, 1361, 1362, 1454; **Ni-B:** 967; **Ni-Ce:** 970; **Ni-Cr:** 31, 328, 372, 373, 564, 613, 872, 1142, 1212, 1408; **Ni-Cr-Mo:** 798; **Ni-Cr-Si:** 179, 454, 897, 1172, 1173, 1232; **Ni-Cu:** 976, 1009, 1388; **Ni-Mn:** 1211; **Ni-Mo:** 980, 1010; **Ni-Si:** 984; **Ni-U:** 1003; **Ni-V:** 1004; **Ni-Zr:** 1006; **Si:** 518, 607, 1245, 1325, 1363; **Si-Mn:** 1237, 1275, 1322; **Si-Ti-V:** 1442; **Ti:** 1394; **U:** 1437; **V:** 1449; **W:** 283, 433, 723, 922, 1416; **W-Cr:** 284, 748, 1045, 1375, 1445; **W-Cr-V:** 285, 942, 1401, 1435; **Zr:** 1508.



## Other Ferrous Alloys

With or without carbon and including some of the high alloy steels

**Cr-Fe:** 286; **Cu-Fe:** 570, 1174, 1195; **Fe-Al:** 128; **Fe-Co:** 1133; **Fe-Co-Cr:** 588; **Fe-Cr:** 9, 173, 364, 381, 507, 561, 596; **Fe-Cr-Co:** 391, 392, 502, 689, 690; **Fe-Cr-Mn:** 1013, 1383; **Fe-Cr-Mo:** 10, 290, 384; **Fe-Cr-Ni:** 329, 385, 591; **Fe-Cr-Si:** 252, 466, 467, 1233, 1234; **Fe-Cu-Al:** 570; **Fe-Mn-Si:** 1201; **Fe-Ni:** 54, 146, 486, 503, 707, 727, 756, 1079, 1099, 1454; **Fe-Ni-Al:** 1230; **Fe-Ni-Cr:** 307, 328, 365, 369, 454, 537, 562, 564, 575, 897, 947, 948, 1172, 1173, 1212, 1232; **Fe-Ni-Cu:** 32, 917, 1089; **Fe-Ni-Mn:** 389, 1211, 1388; **Fe-Si:** 9(*v.* high Si cast iron); **Fe-V:** 140; **Ni-Cr-Fe:** 679, 946, 952, 949, 973; **Ni-Cu-Fe:** 501; **Ni-Fe:** 183, 1072, 1165; **Ni-Fe-Co:** 1073; **Ni-Fe-Cr:** 180, 320, 326, 327, 330, 368, 590, 626, 950, 951, 1093; **Ni-Si-Fe:** 1243; **Sn-Fe-Cu:** 1350.

## Electrical Alloys

Alloys having high resistance, or low temperature coefficient of resistance, *v. also* heat resisting alloys

**Ag-Pt:** 1168; **Cr-Ni:** 1169; **Cu-Fe:** 1174; **Cu-Mn:** 857,<sup>1</sup> 858,<sup>1</sup> 1167, 1170, 1171, 1174, 1175; **Cu-Ni:** 22,<sup>1</sup> 405,<sup>1</sup> 412,<sup>1</sup> 555,<sup>1</sup> 716,<sup>1</sup> 717,<sup>1</sup> 722, 1176; **Cu-Zn:** 545, 856, 1166; **Fe-Cr:** 173, 1013, 1233, 1383; **Fe-Ni:** 146, 389, 397, 486,<sup>2</sup> 503,<sup>2</sup> 564, 575, 707, 947, 948, 1079, 1232, 1388; **Ni-Al:** 1007; **Ni-Cr:** 307, 362, 366, 367, 370, 554, 742, 753, 754, 864, 946, 949, 952, 953, 954, 971, 972, 1008, 1145, 1154, 1160; **Ni-Cu:** 803, 804; **Ni-Fe:** 180, 326, 327, 368, 626, 841, 950, 951, 973, 1093, 1165, 1402; **Ni-Mn:** 64, 699, 830, 832, 848, 849, 850, 1309.

## Corrosion Resisting Alloys

**Co-Ni:** 287, 288, 289; **Co-Cr:** 189; **Co-W:** 687, 688; **Cr-Co:** 188; **Cr-Fe:** 9, 286; **Cu-Al:** 45, 104, 141; **Cu-Ni:** 136, 176, 260, 261, 266, 280, 438, 463, 551, 787, 1213; **Cu-Pb:** 6, 895; **Cu-Si:** 552; **Cu-Sn:** 5, 8, 732; **Cu-Zn:** 175, 259, 790, 1227; **Fe-Cu:** 1197; **Fe-Cr:** 10, 12, 15, 171, 252, 290, 364, 381, 391, 392, 422, 502, 507, 689, 758, 759, 941, 1013, 1198, 1272, 1323, 1324; **Fe-Ni:** 32, 54, 179, 328, 365, 397, 454, 756, 897, 1089, 1172, 1173, 1211, 1212, 1230; **Fe-Si:** 52, 423, 515, 516, 536, 730, 1374; **Ni-Cr:** 187, 316, 720, 953, 954, 1155; **Ni-Cu:** 11, 420, 501, 781, 880, 899, 907, 908, 909, 1057, 1058; **Ni-Fe:** 368; **Ni-Mn:** 440; **Ni-Zn:** 865; **Pb-Cu:** 421; **Pb-Sn:** 7; **Sn-Pb:** 1226.

## Heat Resisting Alloys

**Co-Ni:** 287, 288, 289; **Co-W:** 687, 688; **Cr-Co:** 188, 189; **Cr-Fe:** 286; **Cu-Al:** 45, 104; **Cu-Mn:** 436, 545, 851, 857, 858; **Cu-Ni:** 20, 22, 405, 412, 463, 551, 555, 623, 716, 717, 880; **Cu-Si:** 552; **Cu-Zn:** 704, 852, 856; **Fe-Cr:** 171, 173, 252, 290, 329, 364, 381, 384, 385, 466, 467, 507, 561, 591, 689, 690, 805, 1013, 1233, 1234, 1383; **Fe-Ni:** 146, 179, 328, 365, 369, 397, 454, 562, 564, 707, 756, 947, 948, 1079, 1172, 1173, 1232, 1384, 1454; **Ni-Cr:** 133,

187, 190, 307, 316, 362, 366, 367, 370, 435, 554, 679, 720, 742, 753, 754, 864, 946, 949, 952, 953, 954, 971, 972, 1008, 1057, 1058, 1145, 1154, 1155, 1160; **Ni-Cu:** 880, 899, 908, 909; **Ni-Fe:** 180, 185, 326, 327, 330, 368, 626, 841, 950, 951, 973, 1093, 1402; **Ni-Mn:** 64, 699, 848, 849, 850, 1309.

## Fusible Alloys

143, 461, 546-550, 610, 668, 792, 796, 944, 1023, 1190-1191, 1488.

## Pyrophoric Alloys

181, 182, 718, 719, 762, 896.

## Stellite and Similar Alloys

36, 325, 343, 407, 588, 671, 687, 688, 689, 1068, 1344-1349, 1459.

## Speculums

357, 358, 409, 522, 543, 767, 797, 820, 916, 1037, 1180, 1201, 1308.

## Dental Alloys

351, 377, 464, 649, 752, 1152, 1470, 1484.

## Bearing Alloys

## COPPER BASE

29, 34, 35, 55, 56, 141, 200-218, 331, 335, 342, 456, 457, 458, 459, 469, 500, 514, 519, 521, 541, 553, 556, 615, 745, 761, 768, 769, 965, 1123, 1130, 1328, 1434.

## WHITE METALS

## Aluminum base

**Cu:** 594; **Ni:** 265.

## Lead base

**Ba:** 602, 807; **Ca:** 186, 332, 390, 867, 1433; **Mg:** 676; **Na:** 1011; **Sb:** 144, 145, 219-221, 225-232, 460, 475, 525, 624, 627, 629, 657, 658, 659, 831, 1482; **Sn:** 222, 223, 224, 233, 234, 862, 928, 1040, 1041, 1384.

## Tin base

**Cu:** 498, 560, 675, 692, 740, 1094; **Pb:** 235, 247, 248, 476, 477; **Sb:** 20, 174, 185, 236, 238, 240-246, 474, 485, 739, 935, 1060, 1126; **Zn:** 239.

## Zinc base

**Cu:** 249, 806; **Sb:** 625, 788; **Sn:** 250, 251, 691, 789, 1139, 1204, 1505.

<sup>1</sup> Low temperature coefficient of resistance.

<sup>2</sup> Low thermal expansion coefficient.

## MEANINGS OF SYMBOLS DENOTING TREATMENTS

NOTE: Treatments are denoted by capital letters, with subscripts to indicate modifications. Thus "R<sub>c</sub>" means "cold rolled."

A commonly occurring abbreviation is  $t^\circ/m$ , where  $t^\circ$  is the temperature at which a particular specimen is held for  $m$  units of time (minutes unless otherwise specified).

Care must be used in interpreting some of the data. The effect of heat treatment on properties often varies with the size of the specimen; and although sizes of the test specimens are usually given, it is not always clear whether these have been machined before or after the heat treatment. Where known, dimensions of specimens when heat treated are given in the "Treatment" column.

If symbol is enclosed in a square bracket, [ ], treatment is done in mass, *i.e.*, before machining, but dimensions are not specified.

A	Annealed
A	Annealed drastically
A <sub>b</sub>	Box annealed
A <sub>c</sub>	Close annealed
A <sub>N<sub>2</sub></sub>	Annealed in nitrogen
A <sub>v</sub>	Annealed <i>in vacuo</i>
A <sub>2</sub>	Re-annealed
B	Blued
C	Cooled
C <sub>a</sub>	Cooled in air
C <sub>CaO</sub>	Cooled in lime
C <sub>f</sub>	Cooled in furnace
C <sub>fo</sub>	Cooled in furnace with door open
C <sub>gm</sub>	Cooled in gas muffle
C <sub>m</sub>	Cooled in muffle
C <sub>o</sub>	Cooled in oil
C <sub>q</sub>	Cooled quickly
C <sub>r</sub>	Cooled at moderate rate
C <sub>s</sub>	Cooled slowly
C <sub>t</sub>	Cooled in fireclay tube
C <sub>t<sup>c</sup>/m</sub>	Cooled through critical range at rate of $t^\circ$ per min
C <sub>z</sub>	Cooled in sand
CR	Cherry red heat
Crys.	Single crystal
D	Drawn
D <sub>c</sub>	Drawn, cold
D <sub>d</sub>	Drawn, hard
D <sub>h</sub>	Drawn, hot
DA	Drawn, with annealing
Do	The same
Dp	As deposited
DR	Dark red heat
E	Extruded
F	Forged
F <sub>m</sub>	Forged on mandrel
G	Cast, or as cast
G <sub>c</sub>	Cast, centrifugal
G <sub>gt</sub>	Cast in glass tube
G <sub>hm</sub>	Cast in preheated mold
G <sub>m</sub>	Cast, chill
G <sub>m/2</sub>	Cast, semi-chill
G <sub>phm</sub>	Pressure cast in preheated mold
G <sub>s</sub>	Cast, sand
Gr	Ground
Gr <sub>w</sub>	Ground, wet
H	Hardened
H <sub>a</sub>	Hardened, air
H <sub>o</sub>	Hardened in oil
H <sub>1/2</sub>	Half-hard

## SIGNIFICATION DES SYMBOLES INDIQUANT LES TRAITEMENTS

NOTE: Les traitements sont mentionnés par des lettres majuscules, avec des indices pour indiquer les modifications. Ainsi "R<sub>c</sub>" signifie "laminé à froid."

Une abréviation qui se présente souvent est  $t^\circ/m$  où  $t^\circ$  est la température à laquelle une éprouvette particulière est maintenue pendant  $m$  unités de temps (minutes, à moins d'une indication).

Une certaine attention est nécessaire dans l'interprétation de quelques-unes des données. L'effet du traitement thermique sur les propriétés varie souvent avec les dimensions de l'éprouvette; et quoique les dimensions des éprouvettes essayées soient ordinairement données, il n'est pas toujours évident si celles-ci ont été fabriquées avant ou après le traitement thermique. Les dimensions des éprouvettes traitées thermiquement sont données, lorsqu'elles sont connues, dans la colonne "Treatment."

Si le symbole est compris entre crochets [ ], le traitement est fait en masse, c'est-à-dire avant l'usinage, mais les dimensions ne sont pas spécifiées.

A	Recuit
A	Recuit brutalement
A <sub>b</sub>	Recuit en boîte
A <sub>c</sub>	Recuit en vase clos
A <sub>N<sub>2</sub></sub>	Recuit dans l'azote
A <sub>v</sub>	Recuit dans le vide
A <sub>2</sub>	Double recuit
B	Bleui
C	Refroidi
C <sub>a</sub>	Refroidi dans l'air
C <sub>CaO</sub>	Refroidi dans la chaux
C <sub>f</sub>	Refroidi dans le four
C <sub>fo</sub>	Refroidi dans le four, la porte étant ouverte
C <sub>gm</sub>	Refroidi dans le moufle à gaz
C <sub>m</sub>	Refroidi dans le moufle
C <sub>o</sub>	Refroidi dans l'huile
C <sub>q</sub>	Refroidi rapidement
C <sub>r</sub>	Refroidi d'une façon modérée
C <sub>s</sub>	Refroidi lentement
C <sub>t</sub>	Refroidi dans un tube d'argile réfractaire
C <sub>t<sup>c</sup>/m</sub>	Refroidi dans l'intervalle critique à raison de $t^\circ$ par minute
C <sub>z</sub>	Refroidi dans le sable
CR	Chaleur rouge cerise
Crys.	Cristal unique
D	Étiré
D <sub>c</sub>	Étiré à froid
D <sub>d</sub>	Étiré dur
D <sub>h</sub>	Étiré à chaud
DA	Étiré avec recuit
Do	Le même
Dp	Comme déposé
DR	Chaleur rouge sombre
E	Matricé
F	Forgé
F <sub>m</sub>	Forgé sur mandrin
G	Coulé, ou comme coulé
G <sub>c</sub>	Coulé, centrifugé
G <sub>gt</sub>	Coulé en tube de verre
G <sub>hm</sub>	Coulé en coquille préalablement chauffé
G <sub>m</sub>	Coulé, en coquille
G <sub>m/2</sub>	Coulé, demi-coquille
G <sub>phm</sub>	Coulé sous pression en coquille préalablement chauffé
G <sub>s</sub>	Coulé en sable
Gr	Broyé
Gr <sub>w</sub>	Broyé, humide
H	Durei



# BEDEUTUNG DER DIE BEHANDLUNG ANGEBENDEN ZEICHEN

BEMERKUNG: Die Behandlungen sind durch grosse Buchstaben gekennzeichnet, der Index zeigt dann ihre Modifikation an. Es bedeutet z.B. "R<sub>c</sub>" kalt gewalzt.

Eine häufig vorkommende Abkürzung ist  $t^{\circ}/m$ , in welcher  $t^{\circ}$  die Temperatur bedeutet bei welcher ein bestimmtes Materialstück  $m$  Zeiteinheiten gehalten wurde (Zeit in Minuten, wenn nichts anderes angegeben).

Die Bedeutung einiger Zahlen muss mit Vorsicht gewertet werden. Der Einfluss der Erwärmung auf die Eigenschaft des Materials ändert sich oft mit dessen Ausmessung. Obgleich die letztere meist angegeben ist, ist es nicht immer klar ob die Prüfung vor oder nach der Wärmebehandlung ausgeführt wurde. Wo bekannt, sind die Dimensionen des Materials sobald es in der Hitze behandelt wurde, in der Kolonne unter "Treatment" angegeben.

Ist das Zeichen in einer eckigen Klammer [ ] so bedeutet dies, dass die Behandlung vor der Prüfung ausgeführt wurde, aber die Ausmessung ist nicht näher angegeben.

A	Ausgeglüht
A	Gründlich ausgeglüht
A <sub>b</sub>	In Glühkiste geglüht
A <sub>c</sub>	Unter Luftabschluss geglüht
A <sub>N<sub>2</sub></sub>	In Stickstoff geglüht
A <sub>v</sub>	In Luftleere geglüht
A <sub>2</sub>	Nochmals geglüht
B	Blau angelassen
C	Erkaltet
C <sub>a</sub>	An Luft erkaltet
C <sub>CaO</sub>	In Kalk erkaltet
C <sub>f</sub>	Im Ofen erkaltet
C <sub>fo</sub>	Dito bei geöffneter Tür
C <sub>gm</sub>	Im Gasmuffelofen erkaltet
C <sub>m</sub>	Im Muffelofen erkaltet
C <sub>o</sub>	Im Ölbad erkaltet
C <sub>a</sub>	Rasch erkaltet
C <sub>r</sub>	Verzögert erkaltet (mässig rasch)
C <sub>s</sub>	Langsam erkaltet
C <sub>t</sub>	Im Chamotterohr erkaltet
C <sub>t<sup>o</sup>/m</sub>	Erkaltet mit einer Durchlaufgeschwindigkeit durch die kritischen Punkte von $t^{\circ}/\text{min}$
C <sub>z</sub>	Erkaltet im Sand
CR	Kirschrotwärme
Crys.	Einzelkristall
D	Gezogen
D <sub>c</sub>	Kalt gezogen
D <sub>d</sub>	Hart gezogen
D <sub>h</sub>	Heiss gezogen
DA	Gezogen mit Ausglühen
Do	Dasgl.
Dp	Wie niedergeschlagen
DR	Dunkelrothitze
E	Ausgestossen
F	Geschmiedet
F <sub>m</sub>	Auf dem Dorn geschmiedet
G	Gegossen oder in gegossenem Zustand
G <sub>c</sub>	Zentrifugalguss
G <sub>gt</sub>	In ein Glasrohr gegossen
G <sub>hm</sub>	In vorgewärmter Gussform vergossen
G <sub>m</sub>	Gegossen in Kokille
G <sub>m/2</sub>	Hartguss
G <sub>phm</sub>	In vorgewärmter Gussform nach dem Pressverfahren vergossen
G <sub>s</sub>	In Sand vergossen

# SIGNIFICATO DI SIMBOLI INDICANTI TRATTAMENTI

NOTA: I trattamenti sono designati con lettere maiuscole munite di indice in basso per indicare le modificazioni. Così "R<sub>c</sub>" significa laminato a freddo.

Una abbreviazione frequente è  $t^{\circ}/m$  dove  $t^{\circ}$  è la temperatura alla quale un dato campione è mantenuto per  $m$  unità di tempo (minuti, quando non è diversamente specificato).

Si deve fare attenzione a interpretare alcuni dati. L'effetto del trattamento termico sulle proprietà spesso varia con le dimensioni del provino; e sebbene le dimensioni siano in genere indicate, non sempre è chiaro se i provini sono stati portati a quelle dimensioni dopo o prima il trattamento termico. In quest'ultimo caso le dimensioni del provino sono riportate nella colonna "Treatment."

Quando il simbolo è racchiuso fra parentesi quadra [ ], il trattamento s'intende fatto sul pezzo prima di lavorarlo, e le dimensioni non sono indicate.

A	Ricotto
A	Ricotto a fondo
A <sub>b</sub>	Ricotto in cassetta
A <sub>c</sub>	Ricotto in ambiente chiuso
A <sub>N<sub>2</sub></sub>	Ricotto in azoto
A <sub>v</sub>	Ricotto nel vuoto
A <sub>2</sub>	Ricotto una seconda volta
B	Rinvenuto in modo da assumere il color blu
C	Raffreddato
C <sub>a</sub>	Raffreddato all'aria
C <sub>CaO</sub>	Raffreddato in calce
C <sub>f</sub>	Raffreddato in forno
C <sub>fo</sub>	Raffreddato in forno con porta aperta
C <sub>gm</sub>	Raffreddato in muffola a gas
C <sub>m</sub>	Raffreddato in muffola
C <sub>o</sub>	Raffreddato in olio
C <sub>q</sub>	Raffreddato rapidamente
C <sub>r</sub>	Raffreddato a velocità moderata
C <sub>s</sub>	Raffreddato lentamente
C <sub>t</sub>	Raffreddato in tubo di refrattario
C <sub>t<sup>o</sup>/m</sub>	Raffreddato attraverso l'intervallo critico con una velocità di $t^{\circ}$ al minuto
C <sub>z</sub>	Raffreddato in sabbia
CR	Temperatura del rosso-ciliegia
Crys.	Cristallo singolo
D	Trafilato
D <sub>c</sub>	Trafilato a freddo
D <sub>d</sub>	Trafilato duro
D <sub>h</sub>	Trafilato a caldo
DA	Trafilato con ricottura
Do	Lo stesso
Dp	Come si deposita
DR	Temperatura del rosso-scuro
E	Fatto passare sotto pressione attraverso a una matrice
F	Fucinato
F <sub>m</sub>	Fucinato su mandrino
G	Getto
G <sub>c</sub>	Getto centrifugato
G <sub>gt</sub>	Colato in tubo di vetro
G <sub>hm</sub>	Colato in forma preriscaldato
G <sub>m</sub>	Colato in conchiglia
G <sub>m/2</sub>	Colato in semiconchiglia
G <sub>phm</sub>	Colato sotto pressione in forma preriscaldato
G <sub>s</sub>	Colato in sabbia
Gr	Smerigliato
Gr <sub>w</sub>	Smerigliato alla mola
H	Temprato
H <sub>a</sub>	Temprato in aria
H <sub>o</sub>	Temprato in olio

H <sub>wk</sub>	Hardened, work
Hm	Hammered
J	Tested (at $t^{\circ}\text{C}$ ) or (immediately)
J <sub>a</sub>	Tested in air
J <sub>CO<sub>2</sub></sub>	Tested in CO <sub>2</sub>
J <sub>H<sub>2</sub></sub>	Tested in H <sub>2</sub>
J <sub>la</sub>	Tested in liquid air
J <sub>N<sub>2</sub></sub>	Tested in N <sub>2</sub>
K	Carburized
M	Modified
Ml	Melted
Ml <sub>2</sub>	Remelted
Ml <sub>v</sub>	Melted in vacuo
N	Normalized
N <sub>a</sub>	Normalized in air
N <sub>v</sub>	Normalized <i>in vacuo</i>
Nat	Natural state
O	As received
P	Pickled
P <sub>w</sub>	Pickled and washed
Pl	Plate
Pr	Pressed
Q	Quenched
Q <sub>b</sub>	Quenched in boiling water
Q <sub>h</sub>	Quenched in hot water
Q <sub>i</sub>	Quenched in iced brine
Q <sub>la</sub>	Quenched in liquid air
Q <sub>o</sub>	Quenched in oil
Q <sub>w</sub>	Quenched in water
Q <sub>Pb</sub>	Quenched in lead bath
Q <sub>salt</sub>	Quenched in salt bath
Q <sub>2</sub>	Double quenched
R	Rolled
R <sub>o</sub>	Rolled, cold
R <sub>d</sub>	Rolled, hard
R <sub>h</sub>	Rolled hot
R <sub>s</sub>	Rolled, soft
S	Soaked
S <sub>h</sub>	Soaked in hot bath
Str	Struck (in coin press)
Sv	As for service
Sw	Swaged
Tp	Tempered
Tp <sub>o</sub>	Tempered in oil
Tp <sub>2</sub>	Retempered
Trt	Heat treated
U	Refined
V	Aged
W	Heated to
W <sub>gf</sub>	Heated in gas furnace
W <sub>s</sub>	Heated slowly
W <sub>2</sub>	Reheated
W $t^{\circ}/x$	Heated to $t^{\circ}\text{C}$ and held there for $x$ min
W $t^{\circ}/xh$	Heated to $t^{\circ}\text{C}$ and held there for $x$ hr
W	White heat
Wk	Worked (Wrought)
Wk <sub>o</sub>	Worked, cold
Wk <sub>d</sub>	Worked, hard
Wk <sub>h</sub>	Worked, hot
Wk <sub>s</sub>	Worked, soft
Y	Yellow heat

In addition to the above, the following signs are used to denote position of test specimen in the original ingot, casting, or rolled bar or plate:

	Longitudinal
⊥	Transverse

H <sub>a</sub>	Durci à l'air
H <sub>o</sub>	Durci à l'huile
H <sub>1/2</sub>	Demi dur
H <sub>wk</sub>	Écroui
Hm	Martelé
J	Essayé à ( $t^{\circ}\text{C}$ ) ou (immédiatement)
J <sub>a</sub>	Essayé dans l'air
J <sub>CO<sub>2</sub></sub>	Essayé dans CO <sub>2</sub>
J <sub>H<sub>2</sub></sub>	Essayé dans H <sub>2</sub>
J <sub>la</sub>	Essayé dans l'air liquide
J <sub>N<sub>2</sub></sub>	Essayé dans N <sub>2</sub>
K	Carburé
M	Modifié
Ml	Fondu
Ml <sub>2</sub>	Refondu
Ml <sub>v</sub>	Fondu dans le vide
N	Normalisé
N <sub>a</sub>	Normalisé dans l'air
N <sub>v</sub>	Normalisé dans le vide
Nat	État naturel
O	Comme reçu
P	Décapé à l'acide
P <sub>w</sub>	Décapé et lavé
Pl	Tôle
Pr	Pressé
Q	Trempé
Q <sub>b</sub>	Trempé dans l'eau bouillante
Q <sub>h</sub>	Trempé dans l'eau chaude
Q <sub>i</sub>	Trempé dans saumure glacée
Q <sub>la</sub>	Trempé dans l'air liquide
Q <sub>o</sub>	Trempé dans l'huile
Q <sub>w</sub>	Trempé dans l'eau
Q <sub>Pb</sub>	Trempé dans un bain de plomb
Q <sub>salt</sub>	Trempé dans un bain de sel
Q <sub>2</sub>	Double trempe
R	Laminé
R <sub>c</sub>	Laminé, froid
R <sub>d</sub>	Laminé, dur
R <sub>h</sub>	Laminé, chaud
R <sub>s</sub>	Laminé, mou
S	Bien recuit
S <sub>h</sub>	Bien recuit dans un bain chaud
Str	Frappé (dans matrice à monnaies)
Sv	Comme utilisé
Sw	Étampé
Tp	Revenu
Tp <sub>o</sub>	Revenu à l'huile
Tp <sub>2</sub>	Revenu deux fois
Trt	Traité thermiquement
U	Raffiné
V	Vieilli
W	Chauffé à
W <sub>gf</sub>	Chauffé dans un four à gaz
W <sub>s</sub>	Chauffé lentement
W <sub>2</sub>	Rechauffé
W $t^{\circ}/x$	Chauffé à $t^{\circ}\text{C}$ et maintenu à cette température pendant $x$ minutes
W $t^{\circ}/xh$	Chauffé à $t^{\circ}\text{C}$ et maintenu à cette température pendant $x$ heures
W	Chaleur rouge blanc
Wk	Travaillé
Wk <sub>o</sub>	Travaillé, froid
Wk <sub>d</sub>	Travaillé, dur
Wk <sub>h</sub>	Travaillé, chaud
Wk <sub>s</sub>	Travaillé, mou
Y	Chaleur rouge jaune



Gr	Geschliffen	H <sub>1/2</sub>	Semiduro
Gr <sub>w</sub>	Nass geschliffen	H <sub>wk</sub>	Incrudito
H	Gehärtet	Hm	Lavorato al maglio
H <sub>a</sub>	Luftgehärtet	J	Provato (a t°C) oppure (immediatamente)
H <sub>o</sub>	Ölgehärtet	J <sub>a</sub>	Provato in aria
H <sub>1/2</sub>	Halb gehärtet	J <sub>CO2</sub>	Provato in CO <sub>2</sub>
H <sub>wk</sub>	Kalt gehärtet	J <sub>H2</sub>	Provato in H <sub>2</sub>
Hm	Gehämmert	J <sub>la</sub>	Provato in aria liquida
J	Geprüft (bei t°C) oder (gleich)	J <sub>N2</sub>	Provato in N <sub>2</sub>
J <sub>a</sub>	Geprüft in Luft	K	Carburizzato
J <sub>CO2</sub>	Geprüft in CO <sub>2</sub>	M	Modificato
J <sub>H2</sub>	Geprüft in H <sub>2</sub>	Ml	Fuso
J <sub>la</sub>	Geprüft in flüssiger Luft	Ml <sub>2</sub>	Rifuso
J <sub>N2</sub>	Geprüft in N <sub>2</sub>	Ml <sub>v</sub>	Fuso nel vuoto
K	Gekohlt	N	Normalizzato
M	Geändert	N <sub>a</sub>	Normalizzato all'aria
Ml	Geschmolzen	N <sub>v</sub>	Normalizzato nel vuoto
Ml <sub>2</sub>	Ungeschmolzen	Nat	Stato naturale
Ml <sub>v</sub>	In Luftleere geschmolzen	O	Nelle condizioni in cui è stato ricevuto
N	Normalisiert	P	Pulito con acido
N <sub>a</sub>	In Luft normalisiert	P <sub>w</sub>	Pulito e lavato
N <sub>v</sub>	In Luftleere normalisiert	Pl	Lamiera
Nat	Natürlicher Zustand	Pr	Pressato
O	Wie erhalten	Q	Temprato in un liquido
P	Abgebeizt	Q <sub>b</sub>	Temprato in acqua bollente
P <sub>w</sub>	Dito und gewaschen	Q <sub>h</sub>	Temprato in acqua calda
Pl	Blech	Q <sub>i</sub>	Temprato in acqua salata ghiacciata
Pr	Gepresst	Q <sub>la</sub>	Temprato in aria liquida
Q	Abgeschreckt	Q <sub>o</sub>	Temprato in olio
Q <sub>b</sub>	Dito in kochendem Wasser	Q <sub>w</sub>	Temprato in acqua
Q <sub>h</sub>	Dito in heissem Wasser	Q <sub>Pb</sub>	Temprato in bagno di piombo
Q <sub>i</sub>	Abgelöscht in Eislake	Q <sub>salt</sub>	Temprato in bagno di sali
Q <sub>la</sub>	Dito in flüssiger Luft	Q <sub>2</sub>	Doppia tempra
Q <sub>o</sub>	Dito in Öl	R	Laminato
Q <sub>w</sub>	Dito in Wasser	R <sub>c</sub>	Laminato a freddo
Q <sub>Pb</sub>	Dito im Bleibad	R <sub>d</sub>	Laminato duro
Q <sub>salt</sub>	Dito im Salzbad	R <sub>h</sub>	Laminato a caldo
Q <sub>2</sub>	Zweimal abgeschreckt	R <sub>s</sub>	Laminato dolce
R	Gewalzt	S	Ricotto a fondo
R <sub>c</sub>	Kalt gewalzt	S <sub>h</sub>	Ricotto a fondo in bagno caldo
R <sub>d</sub>	Hart gewalzt	Str	Stampato con pressa a coniare
R <sub>h</sub>	Heiss gewalzt	Sv	Come per servizio
R <sub>s</sub>	Weich gewalzt	Sw	Forgiato su stampo
S	Geweicht	Tp	Rinvenuto
S <sub>h</sub>	Geweicht in heissem Bad	Tp <sub>o</sub>	Rinvenuto in olio
Str	Ins Münzgesenk geschlagen	Tp <sub>2</sub>	Rinvenuto due volte
Sv	Wie zum Gebrauch	Trt	Trattato termicamente
Sw	Im Gesenk nachgeschmiedet	U	Affinato
Tp	Angelassen	V	Invecchiato
Tp <sub>o</sub>	In Öl angelassen	W	Riscaldato a
Tp <sub>2</sub>	Nochmals angelassen	W <sub>gf</sub>	Riscaldato in un forno a gas
Trt	Wärmebehandelt	W <sub>s</sub>	Riscaldato lentamente
U	Raffiniert	W <sub>2</sub>	Riscaldato due volte
V	Gealtert	W <sub>t°/x</sub>	Riscaldato a t°C e mantenuto a questa temperatura per x minuti
W	Erhitzt auf	W <sub>t°/xh</sub>	Riscaldato a t°C e mantenuto a questa temperatura per x ore
W <sub>gf</sub>	Im Gasofen erhitzt	W	Temperatura del bianco
W <sub>s</sub>	Langsam erhitzt	Wk	Lavorato (grezzo)
W <sub>2</sub>	Wiederholt erhitzt	Wk <sub>c</sub>	Lavorato a freddo
W <sub>t°/x</sub>	Erhitzt auf t° u. x Min. lang	Wk <sub>d</sub>	Lavorato duro
W <sub>t°/xh</sub>	Erhitzt auf t° u. x Std. lang	Wk <sub>h</sub>	Lavorato a caldo
W	Weissglut	Wk <sub>s</sub>	Lavorato dolce
Wk	Bearbeitet (geschmiedet)	Y	Temperatura del color giallo
Wk <sub>c</sub>	Kalt geschmiedet		
Wk <sub>d</sub>	Hart geschmiedet		
Wk <sub>h</sub>	Heiss geschmiedet		
Wk <sub>s</sub>	Weich geschmiedet		

↗ Tangential  
↘ Radial

In the case of single crystals, the following are used:

Crys.  $\parallel$  Parallel to crystal axis

Crys.  $\perp$  Perpendicular to crystal axis

### ABBREVIATIONS AND SYMBOLS DENOTING VARIABLES DEFINING A SYSTEM AND THEIR UNITS

$a$	Area of cross section
CS	Compressive stress
Ga	Gage
$l$	Length (gage length in case of tensile specimens)
$l_0$	Original length
$\Delta l$	Increment of length
$p$	Pressure
$P$	Load
SWG	Steel wire gage
Tr.	Trace (in analysis)
$V$	Volume
$\Delta V$	Increment of volume
$V_0$	Original volume
$d$	Diameter
$\Delta d$	Increment of diameter
$d_0$	Original diameter

### MEANINGS OF SYMBOLS DENOTING PROPERTIES

NOTE: Some of these properties are defined on p. viii, and the definitions are here referred to by number as Def. 1, Def. 2, etc.

A, B, C, D, etc. Thermal coefficients of volume expansion;  $v$ . vol. I, p. 36.

$a^2$	Capillary constant; $v$ . vol. I, p. 35
$A_{c1}, A_{c2}, A_{c3}$ $A_{r1}, A_{r2}, A_{r3}$	Critical temperatures or ranges of steels
BHN	
BMR	Brinell hardness number (Def. 12)
$C_{t1}^{t2}$	Bending modulus of rupture, kg/mm <sup>2</sup> (Def. 5)
$d_4^{20}$	Mean specific heat between $t_1^\circ$ and $t_2^\circ$ C, joule/g
$DL_C$	Specific gravity at 20° referred to water at 4°
$E$	Deformation limit in compression, kg/mm <sup>2</sup>
$EL$	Young's modulus, kg/mm <sup>2</sup> (Def. 10)
$EL$	Elongation, % (Def. 7), gage lengths indicated by subscripts as follows: $a = 2$ in., $b = 3$ in., $c = 4$ in., $d = 100$ mm, $f = 180$ mm, $g = 200$ mm, $k = 20$ in., $l = 66.67 \times$ (cross section area) <sup>1/2</sup> , $s = 4 \times$ (cross section area) <sup>1/2</sup>
$EL$	Elastic limit in tension, kg/mm <sup>2</sup> (Def. 2)
$EL_C$	Elastic limit in compression, kg/mm <sup>2</sup> (Def. 2)
$EL_s$	Elastic limit in shear (or torsion), kg/mm <sup>2</sup> (Def. 2)
$EP$	Extrusion pressure, kg/mm <sup>2</sup>
$FL_0$	Endurance limit to fatigue, kg/mm <sup>2</sup> (Def. 17b)
F. P.	Freezing point, °C
$G$	Modulus of elasticity in shear, kg/mm <sup>2</sup> (Def. 11)
IHN	Impact hardness number
IS	Impact strength, kg-m, machines and specimen type indicated by subscripts as follows: $u =$ Izod, B. E. S. A. Std. specimen; $v =$ Charpy, 45°V notch; $w =$ Charpy, keyhole notch; $x =$ Charpy, Mesnager notch; $y =$ Fremont Square notch; $z =$ U. S. N. Bureau of Aeronautics specimen (Def. 16)
IS'	Impact strength, kg-m/cm <sup>2</sup> , on cross section at notch
K	Bulk modulus of elasticity, kg/mm <sup>2</sup>

En plus des signes ci-dessus, les signes suivants sont utilisés pour indiquer la position de l'éprouvette dans le lingot original, dans la gueuse, dans la barre laminée ou la tôle:

$\parallel$  Longitudinal      ↗ Tangential  
 $\perp$  Transversal      ↘ Radial

Dans le cas des cristaux isolés, les signes suivants sont utilisés:

Crys.  $\parallel$  Parallèle à l'axe du cristal

Crys.  $\perp$  Perpendiculaire à l'axe du cristal

### ABRÉVIATIONS ET SYMBOLES INDIQUANT LES VARI- ABLES DÉFINISSANT UN SYSTÈME ET LEURS UNITÉS

$a$	Surface de la section transversale	$p$	Pression
		$P$	Charge
CS	Effort de compression	SWG	Jauge en fil d'acier
Ga	Jauge	Tr.	Traces (en analyse)
$l$	Longueur (longueur entre repères dans le cas d'éprouvettes de traction)	$V$	Volume
		$\Delta V$	Accroissement de volume
$l_0$	Longueur initiale	$V_0$	Volume initial
$\Delta l$	Accroissement de longueur	$d$	Diamètre
		$\Delta d$	Accroissement du diamètre
		$d_0$	Diamètre initial

### SIGNIFICATION DES SYMBOLES INDIQUANT LES PROPRIÉTÉS

NOTE: Quelques-unes de ces propriétés sont définies à page viii et les définitions sont référées ici par un nombre comme suit: Def. 1, Def. 2, etc.

A, B, C, D, etc. Coefficients thermiques de dilatation cubique;  $v$ . vol. I, p. 36

$a^2$  Constante capillaire;  $v$ . vol. I, p. 35

$A_{c1}, A_{c2}, A_{c3}$   
 $A_{r1}, A_{r2}, A_{r3}$  } Températures ou intervalles critiques des aciers

BHN Nombre de dureté Brinell (Def. 12)

BMR Module de rupture à la flexion, kg/mm<sup>2</sup> (Def. 5)

$C_{t1}^{t2}$  Chaleur spécifique moyenne entre  $t_1^\circ$  et  $t_2^\circ$  C, joules/g

$d_4^{20}$  Densité à 20° par rapport à l'eau à 4°

$DL_C$  Limite de déformation à la compression, kg/mm<sup>2</sup>

$E$  Module de Young, kg/mm<sup>2</sup> (Def. 10)

$EL$  Allongement en pourcent (Def. 7), longueur entre repères indiquée par indices comme suit:  $a = 2$  in.;  $b = 3$  in.;  $c = 4$  in.;  $d = 100$  mm,  $f = 180$  mm,  $g = 200$  mm,  $k = 20$  in.,  $l = 66.67 \times$  (section transversale)<sup>1/2</sup>,  $s = 4 \times$  (section transversale)<sup>1/2</sup>

$EL$  Limite élastique à la traction, kg/mm<sup>2</sup> (Def. 2)

$EL_C$  Limite élastique à la compression, kg/mm<sup>2</sup> (Def. 2)

$EL_s$  Limite élastique au cisaillement (ou torsion), kg/mm<sup>2</sup> (Def. 2)

$EP$  Pression de matrice, kg/mm<sup>2</sup>

$FL_0$  Limite d'endurance à la fatigue, kg/mm<sup>2</sup> (Def. 17b)

F. P. Point de congélation, °C

$G$  Module d'élasticité de glissement, kg/mm<sup>2</sup> (Def. 11)

IHN Nombre de dureté au choc

IS Résistance au choc, kg-m. Machines et éprouvettes types indiquées par des indices comme suit:  $u =$  Izod, B. E. S. A. Std. éprouvette type;  $v =$  Charpy, entaille en V 45°;  $w =$  Charpy, entaille en trou de clé;  $x =$  Charpy, entaille Mesnager;  $y =$  entaille carrée, Fremont;  $z =$  éprouvette type du U. S. N. Bureau



Y Gelbhitze

In dem Vorangegangenen werden nach die folgenden Zeichen hinzugefügt, welche die Stellung des Originalblockes, des gegossenen oder gewalzten Stückes, oder der Platte, angeben:

|| Längs  
 ⊥ Quer  
 ↗ Tangential  
 ↘ Radial

Bei Einkristallen bedeuten die Zeichen:

Crys. || Gleichgerichtet zur Kristallachse  
 Crys. ⊥ Senrecht zur Kristallachse

#### ABKÜRZUNGEN UND ZEICHEN DER SYSTEMVARIABLEN UND DEREN EINHEITEN

a Querschnitt (fläche)  
 CS (Druck-) (Press-) spannung  
 Ga Lehre  
 l Messlänge im Falle der Zerreißproben  
 $l_0$  Ursprüngliche Länge  
 $\Delta l$  Zunahme der Länge  
 p Druck  
 P Belastung  
 SWG Stahldrahtlehre  
 Tr. Spuren (in Analyse)  
 V Volumen  
 $\Delta V$  Volumzunahme  
 $V_0$  Ausgangs- oder Ursprungsvolumen  
 d Durchmesser  
 $\Delta d$  Zunahme des Durchmessers  
 $d_0$  Ursprünglicher Durchmesser

#### ZEICHEN FÜR EIGENSCHAFTEN

BEMERKUNG: Einige dieser Eigenschaften sind definiert p. viii. Sie sind unten noch durch die Bemerkung Def. 1, Def. 2, u.s.w. näher angegeben.

A, B, C, D, etc. Koeff. der Wärmeausdehnung des Volumens; siehe vol. I, p. 36

$a^2$  Kapillaritätskonstante; siehe vol. I, p. 35  
 $A_{c1}, A_{c2}, A_{c3}$  } Kritische Temperaturen oder Umwandlungspunkte der Stähle  
 $A_{r1}, A_{r2}, A_{r3}$  }  
 BHN Brinellhärte (Kugeldruckhärte) (Def. 12)  
 BMR Biegefestigkeit, kg/mm<sup>2</sup> (Def. 5)  
 $C_{t1}^{t2}$  Mittlere spez. Wärme zwischen  $t_1^\circ$  und  $t_2^\circ$  C, Joule/g  
 $d_4^{20}$  Spezifisches Gewicht  
 DL<sub>C</sub> Elastizitätsgrenze beim Druckversuch, kg/mm<sup>2</sup>  
 E Young'scher Modul, kg/mm<sup>2</sup> (Def. 10)  
 EL Bruchdehnung in Prozenten der Messlänge (Def. 7), Lehren sind durch Indices angegeben und zwar: a = 2 in., b = 3 in., c = 4 in., d = 100 mm, f = 180 mm, g = 200 mm, k = 20 in.  $l = 66,67 \times \text{Querschnitt}^{1/2}$ ,  $s = 4 \times \text{Querschnitt}^{1/2}$   
 EL Elastizitätsgrenze beim Zugversuch, kg/mm<sup>2</sup> (Def. 2)  
 EL<sub>C</sub> Dito beim Druckversuch, kg/mm<sup>2</sup> (Def. 2)  
 EL<sub>S</sub> Schubelastizitätsgrenze (oder Drehung), kg/mm<sup>2</sup> (Def. 2)  
 EP Ausstossdruck, kg/mm<sup>2</sup>  
 FL<sub>0</sub> Dauerbruchgrenze, kg/mm<sup>2</sup>, (Def. 17b)  
 F. P. Erstarrungspunkt, °C  
 G Elastizitätsmodul für Scherbeanspruchung, kg/mm<sup>2</sup> (Def. 11)  
 IHN Schlaghärte  
 IS Schlagfestigkeit, kg-m. Maschinen und Materialprobe sind durch Indices angegeben, und zwar: u = Izod, B. E. S. A. Std. Probeform; v =

Oltre a queste indicazioni sono pure adoperati i segni seguenti a indicare la posizione dei provini nel lingotto nel getto o nella barra o lamiera originarii:

|| Longitudinale  
 ⊥ Trasversale  
 ↗ Tangenziale  
 ↘ Radiale

Nel caso dei singoli cristalli si usano i seguenti:

Crys. || Parallelo all'asse del cristallo  
 Crys. ⊥ Perpendicolare all'asse del cristallo

#### ABBREVIAZIONI E SIMBOLI INDICANTI VARIABILI CHE DEFINISCONO UN SISTEMA E LORO UNITÀ

a	Area della sezione trasversale	P	Carico
CS	Sforzo di compressione	SWG	Calibro per fili
Ga	Calibro	Tr.	Traccia (in analisi)
l	Lunghezza (calibro di lunghezza nel caso di provini di trazione)	V	Volume
$l_0$	Lunghezza originaria	$\Delta V$	Aumento di volume
$\Delta l$	Aumento di lunghezza	$V_0$	Volume originale
p	Pressione	d	Diametro
		$\Delta d$	Aumento di diametro
		$d_0$	Diametro originario

#### SIGNIFICATO DI SIMBOLI INDICANTI PROPRIETÀ

NOTA: Alcune di queste proprietà sono definite nella p. viii, e alle definizioni è qui fatto riferimento con numeri: Def. 1, Def. 2, ecc.

A, B, C, D, ecc. Coefficiente di temperatura della dilatazione cubica; v., vol. I, p. 36

$a^2$  Costante di capillarità; v. vol. I, p. 35

$A_{c1}, A_{c2}, A_{c3}$  } Temperature critiche o intervalli critici degli acciai  
 $A_{r1}, A_{r2}, A_{r3}$  }

BHN Numero di durezza Brinell (Def. 12)

BMR Modulo di rottura alla flessione, kg/mm<sup>2</sup> (Def. 5)

$C_{t1}^{t2}$  Calore specifico medio tra  $t_1^\circ$  e  $t_2^\circ$  C, joule/g

$d_4^{20}$  Peso specifico a 20° riferito all'acqua a 4°

DL<sub>C</sub> Limite di snervamento alla compressione, kg/mm<sup>2</sup>

E Modulo di Young, kg/mm<sup>2</sup> (Def. 10)

EL Allungamento percentuale (Def. 7), i calibri sono indicati a mezzo di indici scritti di sotto a questo modo: a = 2 in., b = 3 in., c = 4 in., d = 100 mm, f = 180 mm, g = 200 mm, k = 20 in.,  $l = 66,67 \times (\text{l'area della sezione trasversale})^{1/2}$ ,  $s = 4 \times (\text{l'area della sezione trasversale})^{1/2}$

EL Limite elastico alla trazione, kg/mm<sup>2</sup> (Def. 2)

EL<sub>C</sub> Limite elastico alla compressione, kg/mm<sup>2</sup> (Def. 2)

EL<sub>S</sub> Limite elastico al taglio (o torsione), kg/mm<sup>2</sup> (Def. 2)

EP Pressione di matrice, kg/mm<sup>2</sup>

FL<sub>0</sub> Limite di durata alla fatica, kg/mm<sup>2</sup> (Def. 17b)

F. P. Punto di congelamento, °C

G Modulo di elasticità al taglio, kg/mm<sup>2</sup> (Def. 11)

IHN Numero di durezza di resistenza all'urto

IS Resistenza all'urto, kg-m. Macchina e tipo del provino sono indicati con indici scritti di sotto nella maniera che segue: u = Izod, provino B. E. S. A. Std.; v = Charpy, con intaglio V a 45°; w = Charpy, con intaglio buco della serratura; x = Charpy, con intaglio Mesnager; y = intaglio quadrato di Fremont; z = provino dello U. S. N. Bureau of Aeronautics (Def. 16)

IS' Resistenza all'urto, kg/cm<sup>2</sup>, sulla sezione utile

$k_{t_1}^{t_2}$	Mean thermal conductivity between $t_1^\circ$ and $t_2^\circ\text{C}$ , joules $\text{cm}^{-2} \text{sec}^{-1} (^\circ\text{C}, \text{cm}^{-1})$	$IS'$	of Aeronautics (Def. 16)
$L_F$	Latent heat of fusion, kilojoule/g-atom	$K$	Résistance au choc, $\text{kg-m/cm}^2$ sur la section à l'entaille
$L_V$	Latent heat of vaporization, kilojoule/g-atom	$k_{t_1}^{t_2}$	Module d'élasticité apparent, $\text{kg/mm}^2$
$l_V$	Latent heat of vaporization, kilojoule/g	$L_F$	Conductibilité thermique moyenne entre $t_1^\circ$ et $t_2^\circ\text{C}$ , joules $\text{cm}^{-2} \text{sec}^{-1} (^\circ\text{C}, \text{cm}^{-1})$
$L_T$	Latent heat of transformation, kilojoule/g-atom	$L_V$	Chaleur latente de fusion, kilojoules/g-atome
$LCH$	Ludwik cone hardness	$l_V$	Chaleur latente de vaporisation, kilojoules/g-atome
$M$	Molecular weight	$L_T$	Chaleur latente de transformation, kilojoules/g-atome
$M. P.$	Melting point, $^\circ\text{C}$	$LCH$	Dureté Ludwik cone
$MS$	Mean stress	$M$	Poids moléculaire
$MSH$	Martens scratch hardness	$M. P.$	Point de fusion, $^\circ\text{C}$
$No. B$	Number of bends to fracture (Def. 15)	$MS$	Effort moyen
$PL$	Proportional limit in tension, $\text{kg/mm}^2$ (Def. 1)	$MSH$	Dureté Martens rayure
$PL_C$	Proportional limit in compression, $\text{kg/mm}^2$ (Def. 1)	$No. B$	Nombre de pliages jusqu'à rupture (Def. 15)
$PL_S$	Proportional limit in shear (or torsion), $\text{kg/mm}^2$ (Def. 1)	$PL$	Limite de proportionnalité à la traction, $\text{kg/mm}^2$ (Def. 1)
$PS$	Proof stress, $\text{kg/mm}^2$	$PL_C$	Limite de proportionnalité à la compression, $\text{kg/mm}^2$ (Def. 1)
$R$	Endurance range, $\text{kg/mm}^2$ (Def. 17e)	$PL_S$	Limite de proportionnalité au cisaillement (ou torsion), $\text{kg/mm}^2$ (Def. 1)
$RA$	Reduction in area, % (Def. 8)	$PS$	Effort d'épreuve, $\text{kg/mm}^2$
$RHN$	Rockwell hardness number	$R$	Amplitude d'endurance, $\text{kg/mm}^2$ (Def. 17e)
$ScH$	Scleroscope hardness (Def. 13)	$RA$	Striction, % (Def. 8)
$Shr.$	Mold shrinkage, %	$RHN$	Nombre de dureté Rockwell
$TMR$	Torsional modulus of rupture, $\text{kg/mm}^2$ (Def. 6)	$ScH$	Dureté au scléroscope (Def. 13)
$TSH$	Turner scratch hardness	$Shr.$	Retrait au moulage, %
$Tw$	Twist in torsion test, $^\circ/\text{cm}$ , unless total twist is given	$TMR$	Module de torsion à la rupture, $\text{kg/mm}^2$ (Def. 6)
$UBM$	Ultimate bending moment	$TSH$	Dureté Turner à la rayure
$UCS$	Ultimate compressive strength, $\text{kg/mm}^2$ (Def. 4)	$Tw$	Torsion dans l'essai de torsion $^\circ/\text{cm}$ , à moins que la torsion totale ne soit donnée
$USS$	Ultimate shearing strength (measured directly), $\text{kg/mm}^2$ (Def. 4)	$UBM$	Moment de flexion ultime
$USS_C$	Ultimate shearing strength, (computed from torsion test), $\text{kg/mm}^2$ (Def. 6, second equation)	$UCS$	Résistance à la compression, $\text{kg/mm}^2$ (Def. 4)
$UTS$	Ultimate tensile strength, $\text{kg/mm}^2$ (Def. 4)	$USS$	Résistance au cisaillement (mesurée directement), $\text{kg/mm}^2$ (Def. 4)
$UWB$	Ultimate work of bending, $\text{kg-m}$	$USS_C$	Résistance au cisaillement (déduite de l'essai de torsion), $\text{kg/mm}^2$ (Def. 6, deuxième équation)
$v$	Specific volume, $\text{g}^{-1}$	$UTS$	Résistance à la traction, $\text{kg/mm}^2$ (Def. 4)
$V. P.$	Vapor pressure	$UWB$	Travail ultime de flexion, $\text{kg-m}$
$YP$	Yield point in tension, $\text{kg/mm}^2$ (Def. 3)	$v$	Volume spécifique, $\text{g}^{-1}$
$YPC$	Yield point in compression, $\text{kg/mm}^2$ (Def. 3)	$V. P.$	Pression de vapeur
$YPS$	Yield point in shear (or torsion), $\text{kg/mm}^2$ (Def. 3)	$YP$	Limite d'étirage ou d'écoulement à la traction, $\text{kg/mm}^2$ (Def. 3)
$\alpha, \beta, \gamma, \delta, \text{etc.}$	Thermal coefficients of linear expansion; <i>v. p.</i> 459	$YPC$	Limite d'étirage à la compression, $\text{kg/mm}^2$ (Def. 3)
$\gamma$	Surface tension; <i>v. vol. I</i> , p. 42.	$YPS$	Limite de cisaillement (ou de torsion), $\text{kg/mm}^2$ (Def. 3)
$\epsilon$	Per cent compression (under stated load)	$\alpha, \beta, \gamma, \delta, \text{etc.}$	Coefficients thermiques de dilatation linéaire; <i>v. p.</i> 459
$\eta$	Tangential or fluid coefficient of viscosity; <i>v. vol. I</i> , p. 42	$\gamma$	Tension de surface; <i>v. vol. I</i> , p. 42
$\xi$	Normal coefficient of viscosity	$\epsilon$	Pourcent de compression (sous une charge donnée)
$\lambda$	Poisson's ratio (Def. 9)	$\eta$	Coefficient de viscosité, tangentiel ou fluide, <i>v. vol. I</i> , p. 42
$\psi_p$	$\frac{1}{\chi} \left( \frac{d\chi}{dp} \right)_t$ (Temperature constant)	$\xi$	Coefficient de viscosité normal
$\psi_t$	$\frac{1}{\chi} \left( \frac{d\chi}{dt} \right)_p$ (Pressure constant)	$\lambda$	Coefficient de Poisson (Def. 9)
$\chi$	Compressibility (atmospheres) $^{-1}$	$\psi_p$	$\frac{1}{\chi} \left( \frac{d\chi}{dp} \right)_t$ (Température constante)
		$\psi_t$	$\frac{1}{\chi} \left( \frac{d\chi}{dt} \right)_p$ (Pression constante)
		$\chi$	Compressibilité (atmosphères) $^{-1}$



	Charpy, V-Kerbe, 45°; w = Charpy, Schlüssel-Rille; x = Charpy, Mesnager-Rille; y = Fremont-Rille mit quadratischen Querschnitt; z = Probeform des U. S. N. Bureau of Aeronautics (Def. 16)	K	Modulo di elasticità alla compressione, kg/mm <sup>2</sup>
IS	Schlagfestigkeit, kg-m/cm <sup>2</sup>	k <sub>t1</sub> <sup>2</sup>	Conducibilità termica media tra t <sub>1</sub> <sup>o</sup> e t <sub>2</sub> <sup>o</sup> C, joule cm <sup>-2</sup> sec <sup>-1</sup> (°C, cm <sup>-1</sup> )
K	Durchschnittlicher Elastizitätsmodul, kg/mm <sup>2</sup>	L <sub>F</sub>	Calore latente di fusione, kilojoule/g-atomo
k <sub>t1</sub> <sup>2</sup>	Mittlere Wärmeleitfähigkeit zwischen t <sub>1</sub> <sup>o</sup> und t <sub>2</sub> <sup>o</sup> C, Joule cm <sup>-2</sup> sec <sup>-1</sup> (°C, cm <sup>-1</sup> )	L <sub>V</sub>	Calore latente di evaporazione, kilojoule/g-atomo
L <sub>F</sub>	Schmelzwärme, Kilojoule/g-atom.	l <sub>V</sub>	Calore latente di evaporazione, kilojoule/g
L <sub>V</sub>	Verdampfungswärme, Kilojoule/g-atom.	L <sub>T</sub>	Calore latente di trasformazione, kilojoule/g-atomo
l <sub>V</sub>	Verdampfungswärme, Kilojoule/g	LCH	Durezza al cono Ludwik
L <sub>T</sub>	Umwandlungswärme, Kilojoule/g-atom.	M	Peso molecolare
LCH	Kegelhärte nach Ludwik	M. P.	Punto di fusione, °C
M	Molekulargewicht	MS	Sforzo medio
M. P.	Schmelzpunkt, °C	MSH	Durezza alla scalfittura secondo Martens
MS	Mittlerer Druck	No. B	Numero di piegature per arrivare a frattura (Def. 15)
MSH	Ritzhärte nach Martens	PL	Limite di proporzionalità alla tensione, kg/mm <sup>2</sup> (Def. 1)
No. B	Zahl der Biegungen (Def. 15)	PL <sub>C</sub>	Limite di proporzionalità alla compressione, kg/mm <sup>2</sup> (Def. 1)
PL	Proportionalitätsgrenze beim Zugversuch, kg/mm <sup>2</sup> (Def. 1)	PL <sub>S</sub>	Limite di proporzionalità al taglio (o torsione), kg/mm <sup>2</sup> (Def. 1)
PL <sub>C</sub>	Dito beim Druckversuch, kg/mm <sup>2</sup> (Def. 1)	PS	Carico di prova, kg/mm <sup>2</sup>
PL <sub>S</sub>	Dito beim Schubversuch (oder Drehung), kg/mm <sup>2</sup> (Def. 1)	R	Ampiezza di durata alla fatica, kg/mm <sup>2</sup> (Def. 17e)
PS	Prüfspannung, kg/mm <sup>2</sup>	RA	Riduzione di area percentuale (Def. 8)
R	Dauerbruchfestigkeit für bestimmte Spannungswechsel, kg/mm <sup>2</sup> (Def. 17e)	RHN	Numeri di durezza Rockwell
RA	Brucheinschnürung in % (Def. 8)	ScH	Durezza scleroscopica (Def. 13)
RHN	Rockwellhärtezah	Shr.	Ritiro percentuale nella forma
ScH	Skleroskophärte (Def. 13)	TMR	Modulo di rottura alla torsione, kg/mm <sup>2</sup> (Def. 6)
Shr.	Schwindung in %	TSH	Durezza alla scalfittura secondo Turner
TMR	Drehfestigkeit, kg/mm <sup>2</sup> (Def. 6)	Tw	Angolo di torsione espresso in gradi per centimetro, a meno che non sia data la torsione totale
TSH	Ritzhärte nach Turner	UBM	Carico di rottura alla flessione
Tw	Verdrehung in °/cm beim Drehversuch	UCS	Carico di rottura per compressione, kg/mm <sup>2</sup> (Def. 4)
UBM	Biegungshöchstmoment	USS	Carico di rottura per taglio (misura direttamente), kg/mm <sup>2</sup> (Def. 4)
UCS	Druckfestigkeit, kg/mm <sup>2</sup> (Def. 4)	USS <sub>C</sub>	Carico di rottura per taglio (calcolato dal saggio di torsione), kg/mm <sup>2</sup> (Def. 6, equazione secondo)
USS	Scherfestigkeit, kg/mm <sup>2</sup> (Def. 4)	UTS	Carico di rottura alla trazione, kg/mm <sup>2</sup> (Def. 4)
USS <sub>C</sub>	Dito durch Drehversuch bestimmt, kg/mm <sup>2</sup> (Def. 6, zweite Gleichung)	UWB	Lavoro di rottura per flessione, kg-m
UTS	Zugfestigkeit, kg/mm <sup>2</sup> (Def. 4)	v	Volume specifico, g <sup>-1</sup>
UWB	Grösstbiegearbeit, kg-m	V. P.	Tensione di vapore
v	Spez. Volumen, g <sup>-1</sup>	YP	Limite di snervamento alla trazione, kg/mm <sup>2</sup> (Def. 3)
V. P.	Dampfdruck	YP <sub>S</sub>	Limite di snervamento alla compressione, kg/mm <sup>2</sup> (Def. 3)
YP	Fliessgrenze, kg/mm <sup>2</sup> (Def. 3)	YP <sub>S</sub>	Limite di snervamento al taglio (o torsione), kg/mm <sup>2</sup> (Def. 3)
YP <sub>C</sub>	Quetschgrenze, kg/mm <sup>2</sup> (Def. 3)	α, β, γ, δ, ecc.	Coefficienti di temperatura della dilatazione lineare; v. p. 459
YP <sub>S</sub>	Fliessgrenze beim Scher- (Dreh-) versuch, kg/mm <sup>2</sup> (Def. 3)	γ	Tensione superficiale; v. vol. I, p. 42
α, β, γ, δ, etc.	Linearer Wärmeausdehnungskoeffizient; siehe, p. 459	ε	Compressione percentuale (sotto un carico statico)
γ	Oberflächenspannung; siehe vol. I, p. 42	η	Coefficiente tangenziale o fluido di viscosità; v. vol. I, p. 42
ε	Prozent Zusammenpressung unter statischer Belastung	ξ	Coefficiente normale di viscosità
η	Tangential- oder Viskositäts-Koeffizient; siehe vol. I, p. 42	λ	Rapporto di Poisson (Def. 9)
ξ	Normaler Viskositätskoeffizient	ψ <sub>p</sub>	$\frac{1}{\chi} \left( \frac{dx}{dp} \right)_t$ (Costante di temperatura)
λ	Verhältnis nach Poisson (Def. 9)	ψ <sub>t</sub>	$\frac{1}{\chi} \left( \frac{dx}{dt} \right)_p$ (Costante di pressione)
ψ <sub>p</sub>	$\frac{1}{\chi} \left( \frac{dx}{dp} \right)_t$ (Temp. Konst.)	χ	Kompressibilität (atmosph.) <sup>-1</sup>
ψ <sub>t</sub>	$\frac{1}{\chi} \left( \frac{dx}{dt} \right)_p$ (Druck Konst.)		
χ	Kompressibilität (atmosph.) <sup>-1</sup>		

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## INTRODUCTION

The vapor phase is not considered, vapor pressure being very small with respect to atmospheric pressure with few exceptions, such as As.

The liquid phase is denoted by Liq., or if more than one liquid phase exists, by Liq. I, Liq. II, etc.

Crystal phases are designated as follows:

A metal or intermetallic compound by its chemical formula.

A solid solution of A in B by (A, B).

If A is a compound, this does not mean necessarily that molecules of A exist in solution; most X-rays data are to the contrary. Crystals of the composition A, however, do separate from the solid solution.

A solid solution of A and B in all proportions by [A, B].

A solid solution of A or B in the compound  $A_xB_y$  by  $(A_xB_y)$ .

A series of different solid solutions by  $\alpha$ ,  $\beta$ ,  $\gamma$ ,  $\delta$ , etc., their composition being stated if known.

A mixture of A and B by A + B.

A binary eutectic in a ternary system by e.

A ternary eutectic by E.

The eutectic temperature of binary alloys is indicated by a dot and dash line.

All temperatures are in °C, and unless otherwise indicated all compositions are in weight %.

## ALUMINIUM ALLOYS

M. L. V. GAYLER

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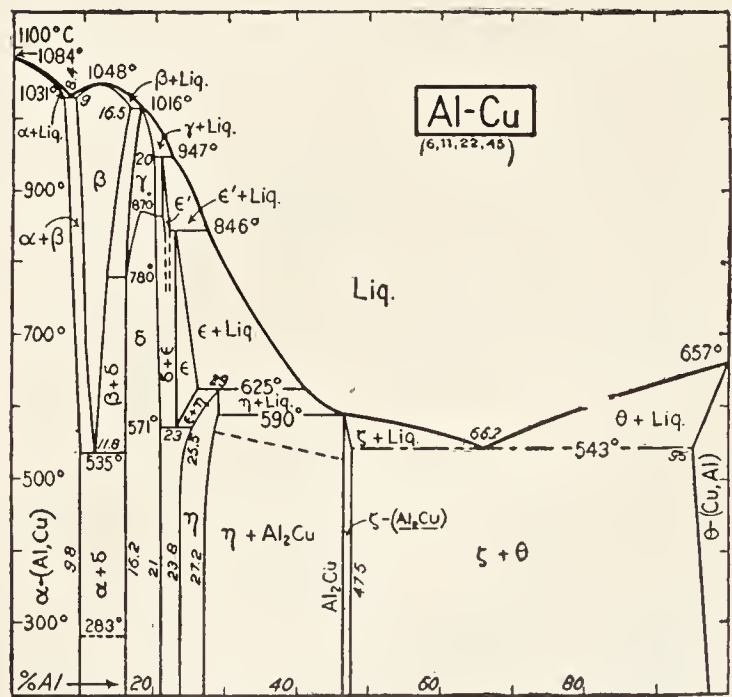
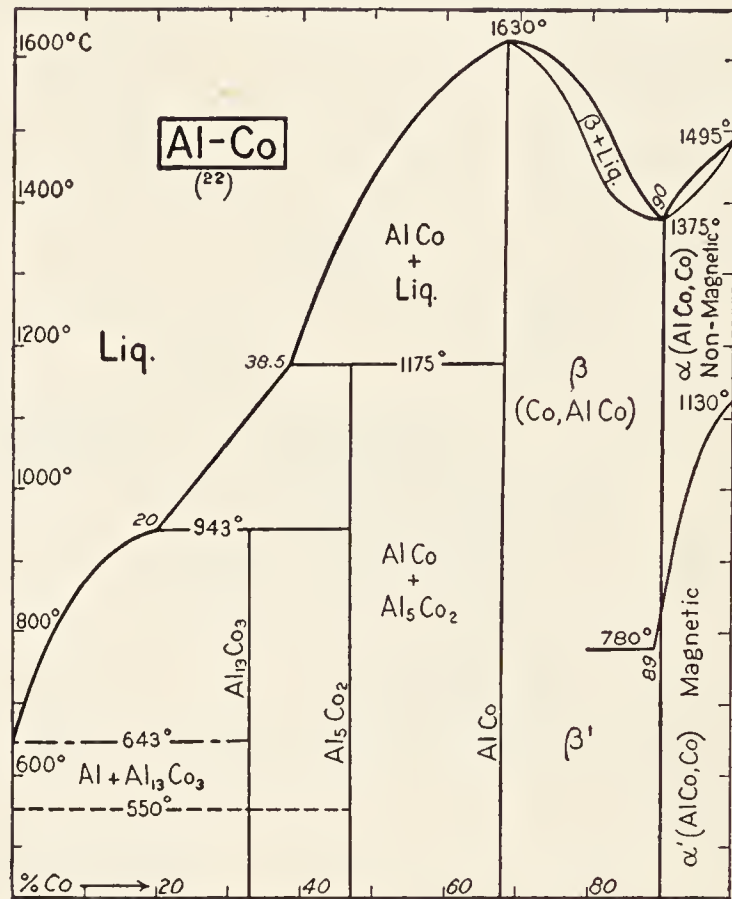
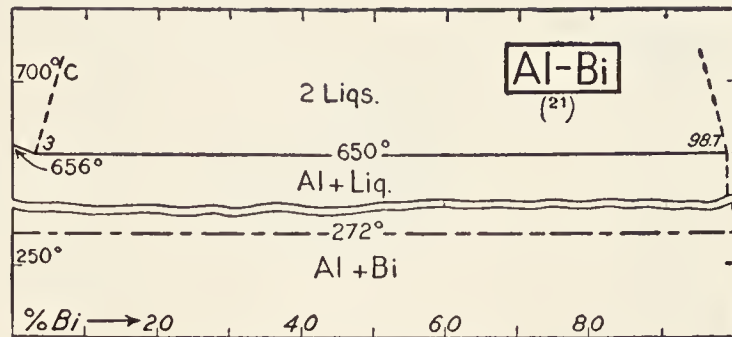
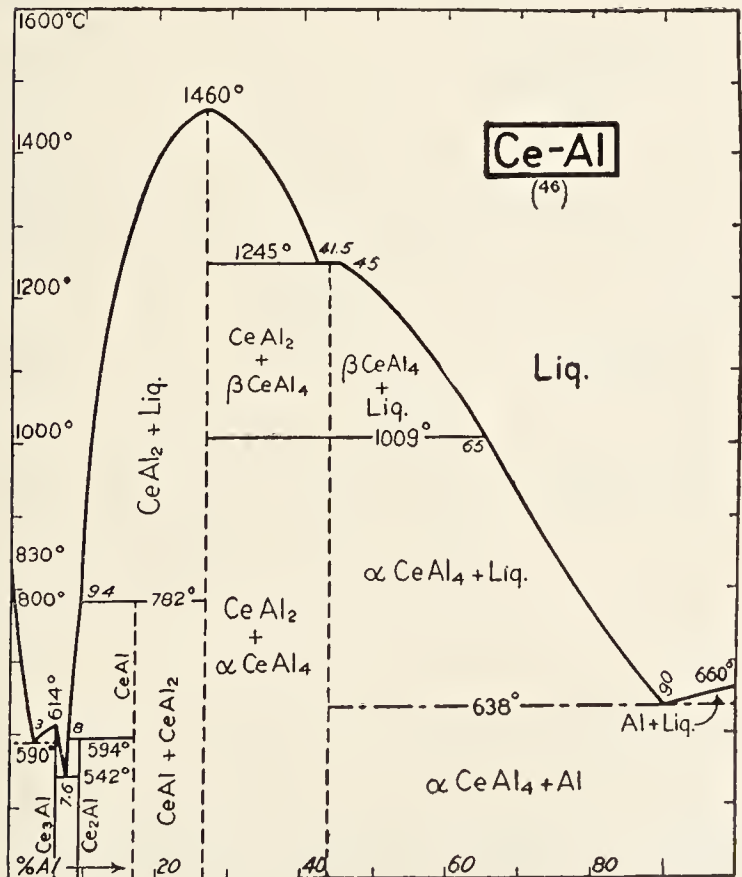
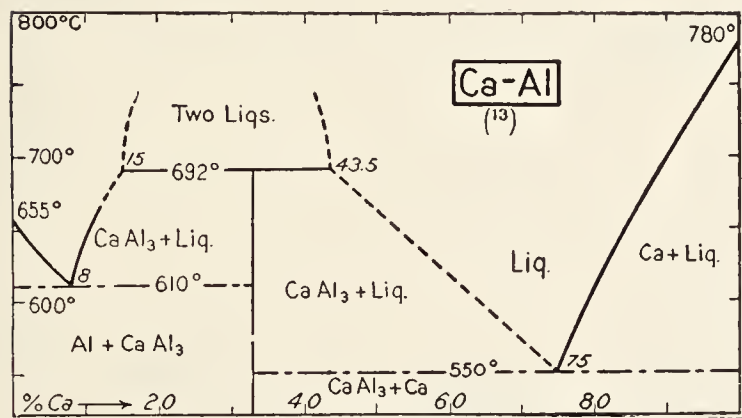
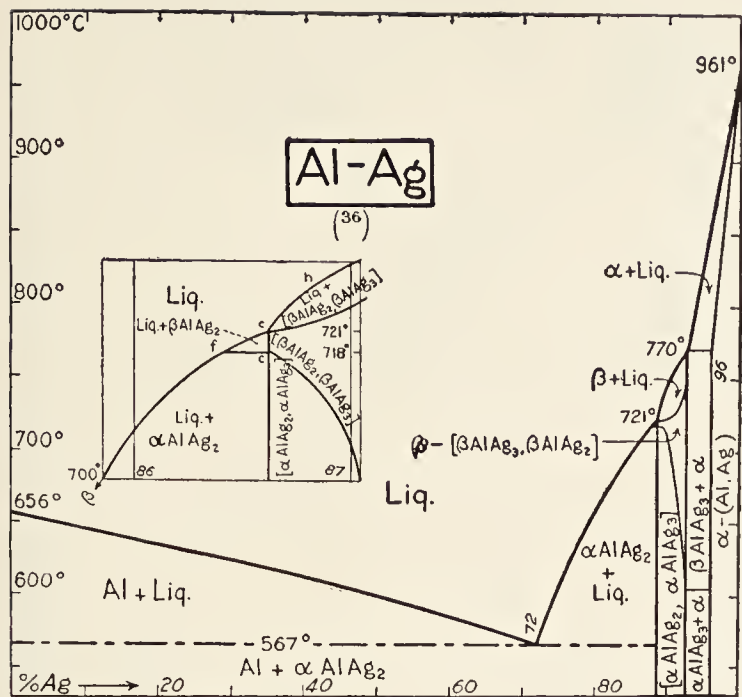
\* Two immiscible liquid phases.

## LITERATURE

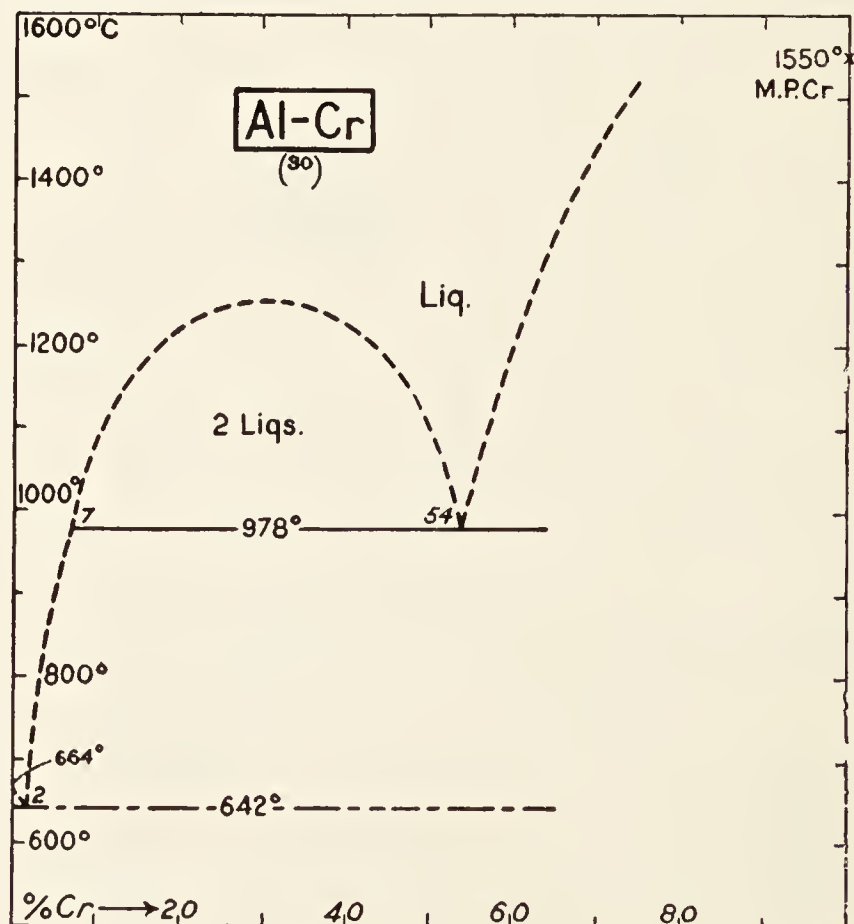
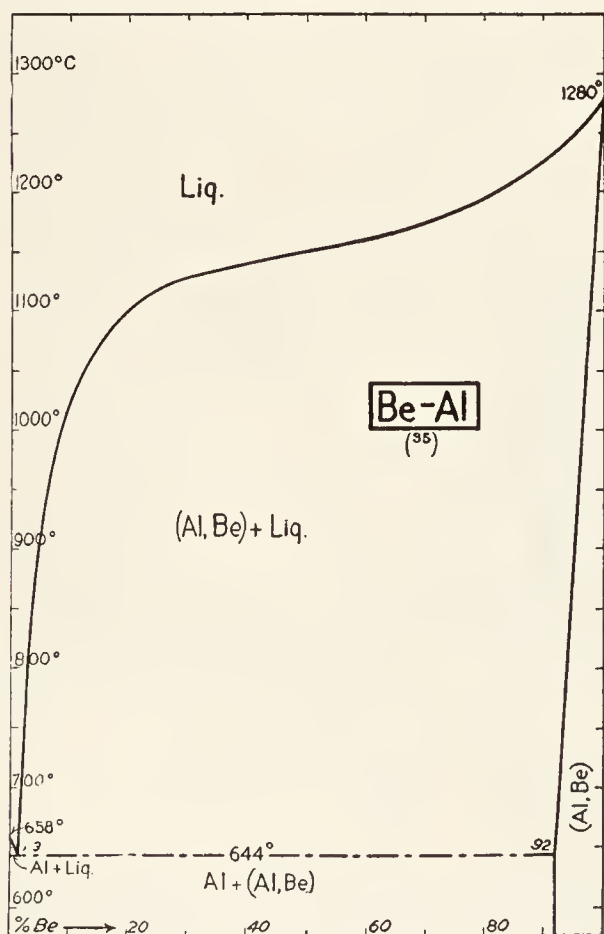
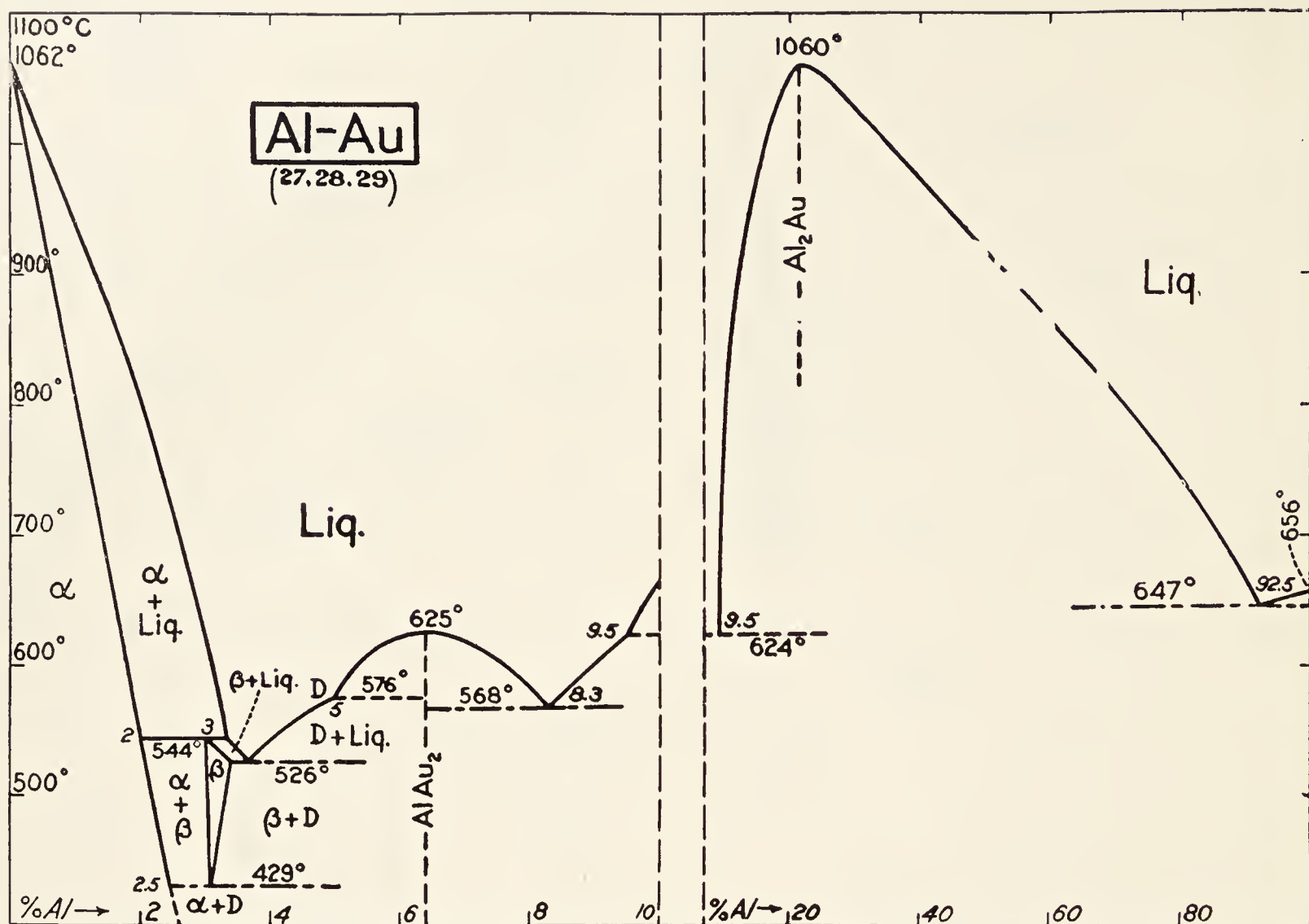
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- (1) Andrews and Edwards, 5, 82: 568; 09. (1.1) Assmann, 95, 18: 51; 26. (2) Austin and Murphy, 47, 29: 327; 23. (3) Bingham and Haughton, 47, 29: 71; 23. (4) Budgen, 4, 125: 1642; 24. (5) Campbell and Matthews, 1, 24: 253; 02. (6) Carpenter and Edwards, 403, 1907 I: 204. (7) Carpenter and Edwards, 95, 2: 209; 12. (8) Chikashige and Aoki, 429, 2: 249; 17. (9) Chikashige and Nosé, 429, 2: 227; 17. (10) Chouriguine, 74, 9: 874; 12. (11) Curry, 50, 11: 425; 07. (11.1) Dix and Richardson, 80, Preprint 1534-E; 26. (12) Doerneckel, 93, 48: 185; 06. (13) Donski, 93, 57: 185; 08. (14) Edwards, 33, 28: 165; 23. (15) Eger, 95, 4: 29; 13. (15.1) Eger, 95, 53: 545; 23. (16) Erckelens, 187, 20: 206; 23. (17) Fraenkel, 93, 58: 154; 08. (18) Gayler, 47, 28: 213; 22. (19) Gayler, 47, 29: 507; 23. (20) Gayler, 47, 30: 139; 23. (21) Gwyer, 93, 49: 311; 06. (22) Gwyer, 93, 57: 113; 08. (23) Hanson and Gayler, 47, 24: 201; 20. (24) Hanson and Gayler, 47, 26: 321; 21. (25) Hanson and Gayler, 47, 27: 267; 22. (26) Haughton and Bingham, 5, 99: 47; 21. (27) Heycock and Neville, 62, 194: 201; 00. (28) Heycock and Neville, 62, 214: 267; 14. (29) Heycock and Neville, 5, 90: 560; 14. (30) Hindricks, 93, 59: 414; 08. (30.1) Honda and Ishigaki, 159, 14: 219; 25. (30.2) Isihara, 159, 15: 209; 26. (31) von Jares, 95, 10: 1; 19. (32) Kurnakov, Urasov and Grigorjev, 93, 125: 207; 22. (33) Losana and Carozzi, 36, 53: 546; 23. (34) Mathewson, 93, 48: 191; 06. (35) Oesterheld, 93, 97: 6; 16. (36) Petrenko, 93, 46: 49; 05. (37) Roberts, 4, 105: 1383; 14. (38) Rosenhain and Archbutt, 62, 211 A: 315; 11. (39) Rosenhain and Archbutt, 5, 85: 389; 11. (40) Rosenhain, Archbutt and Hanson, 403, 1921 II: 699. (41) Rosenhain and Lantsberry, 403, 1910 I: 119. (42) Smith, 93, 56: 109; 07. (43) Smits and de Gruyter, Univ. of Amsterdam, O. (44) Stockdale, 47, 28: 273; 22. (45) Stockdale, 47, 31: 275; 24. (46) Vogel, 93, 75: 41; 12. (47) Vogel, 93, 107: 265; 19.

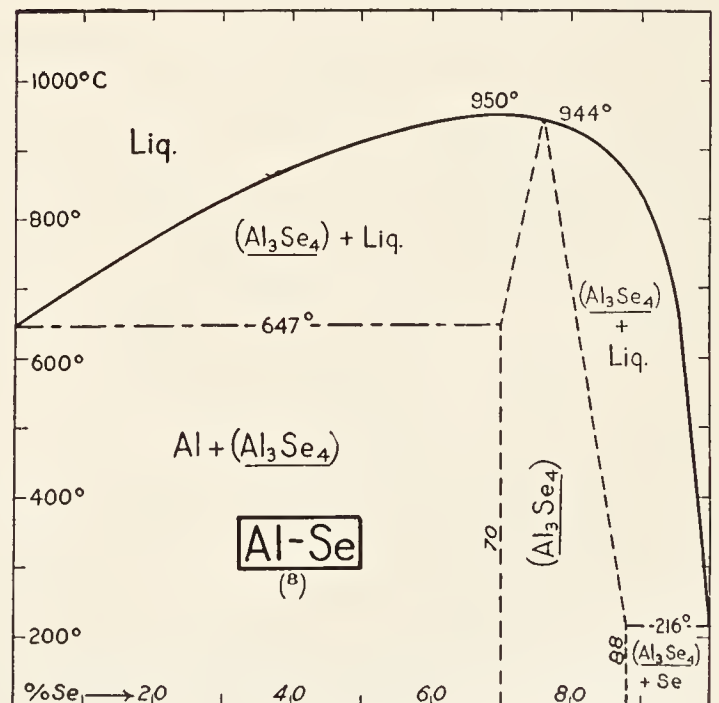
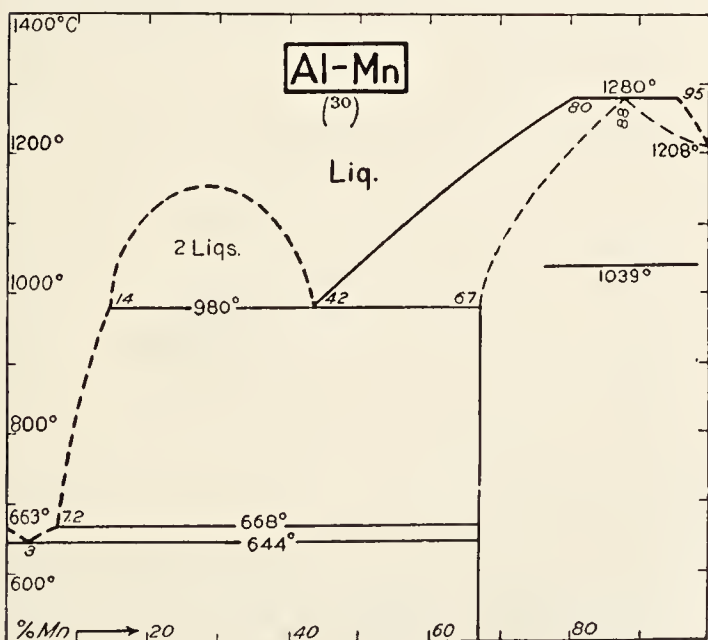
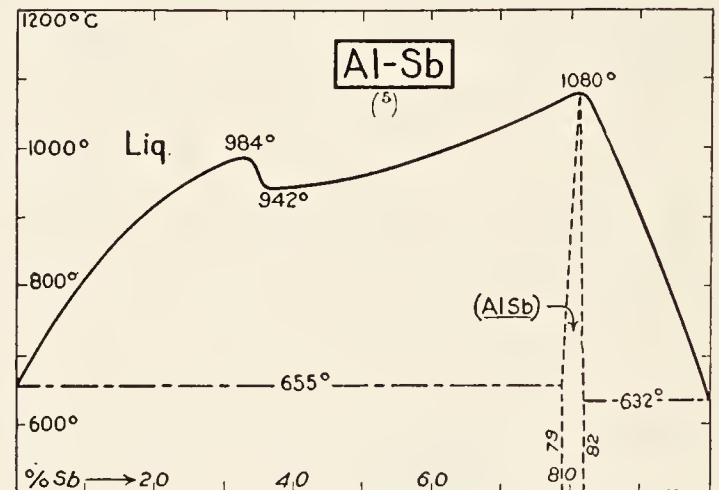
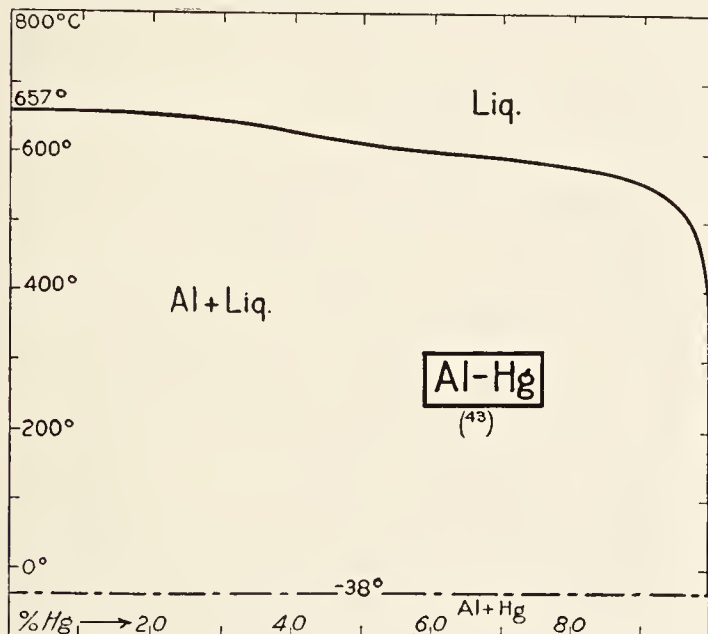
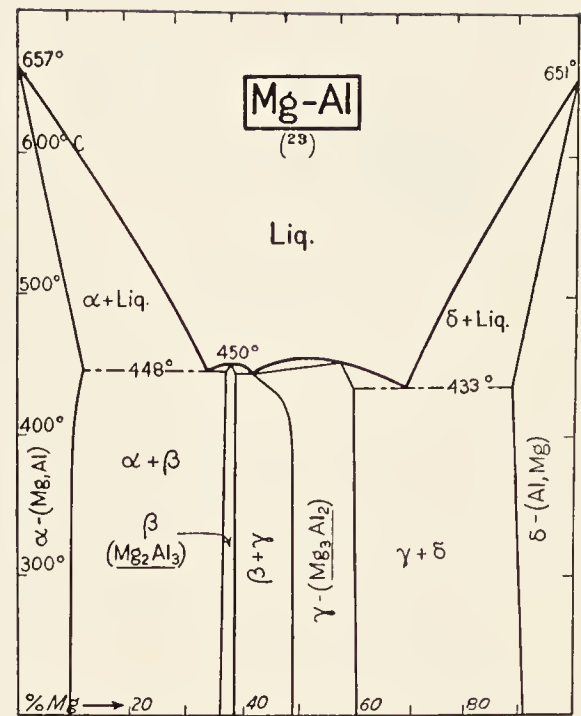
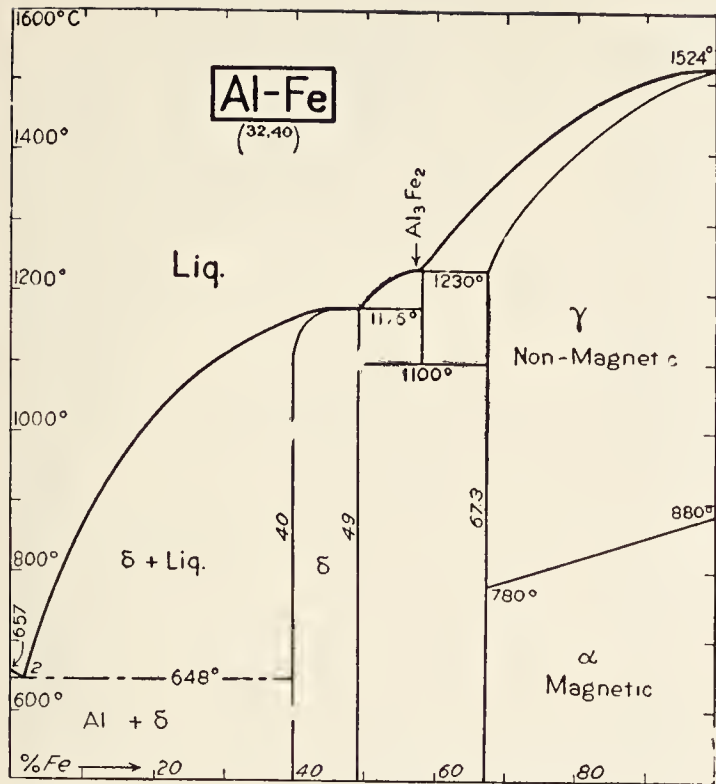


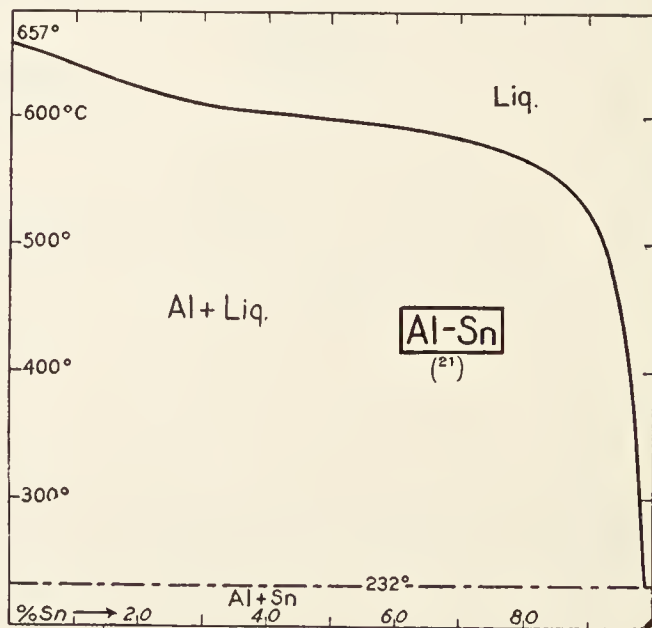
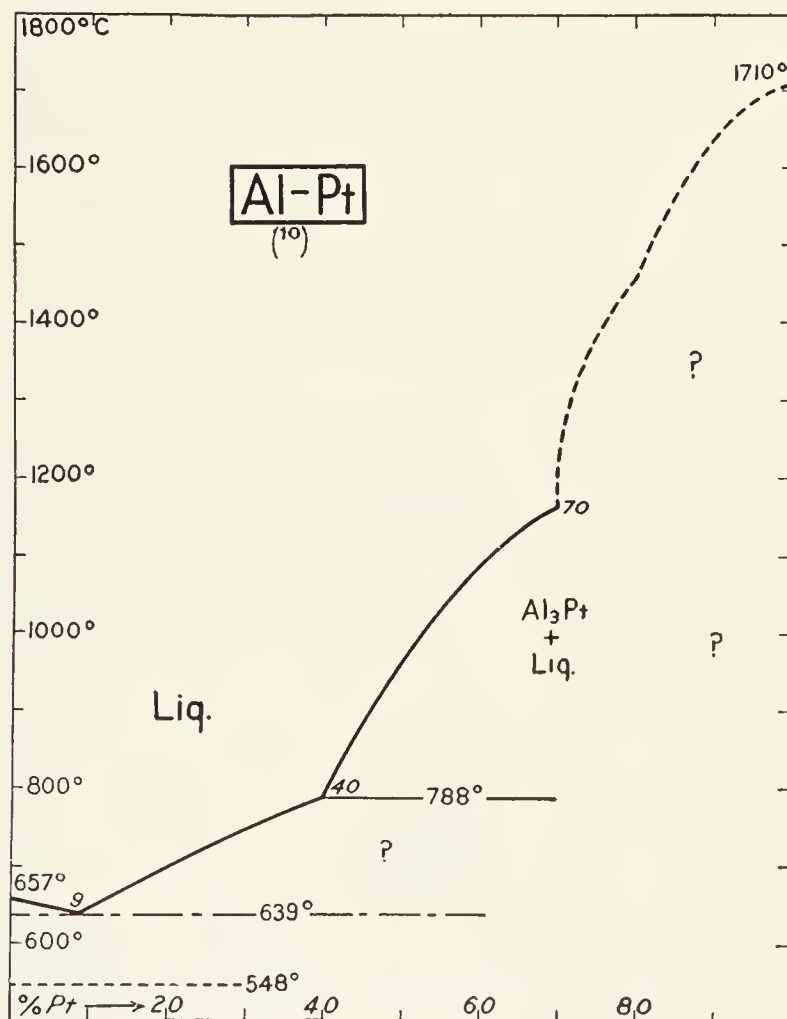
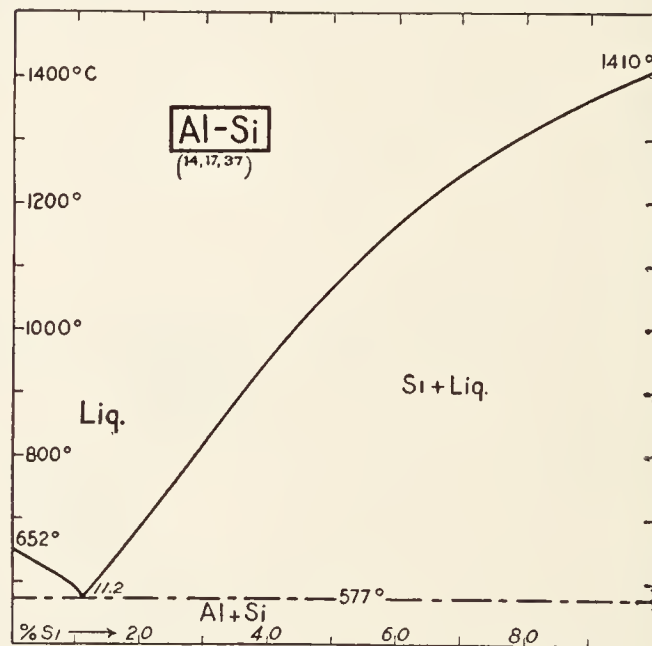
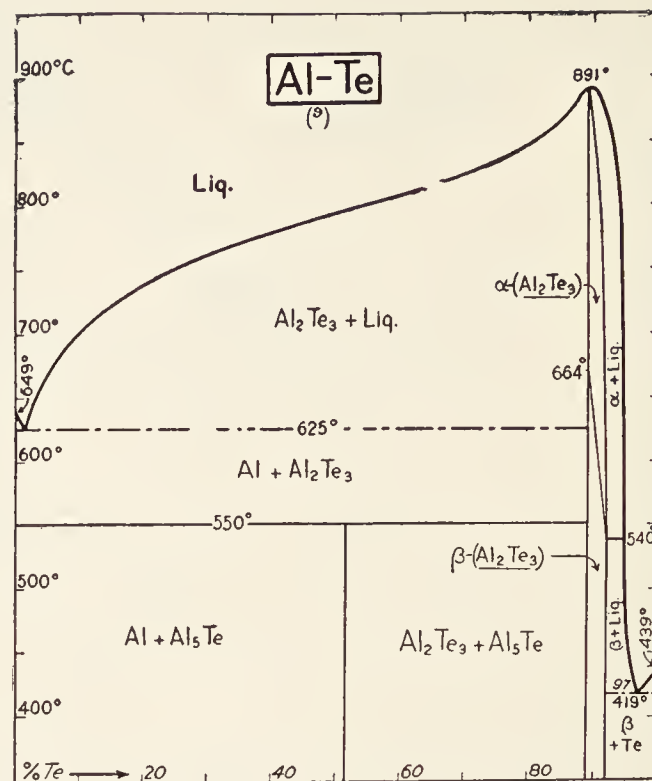
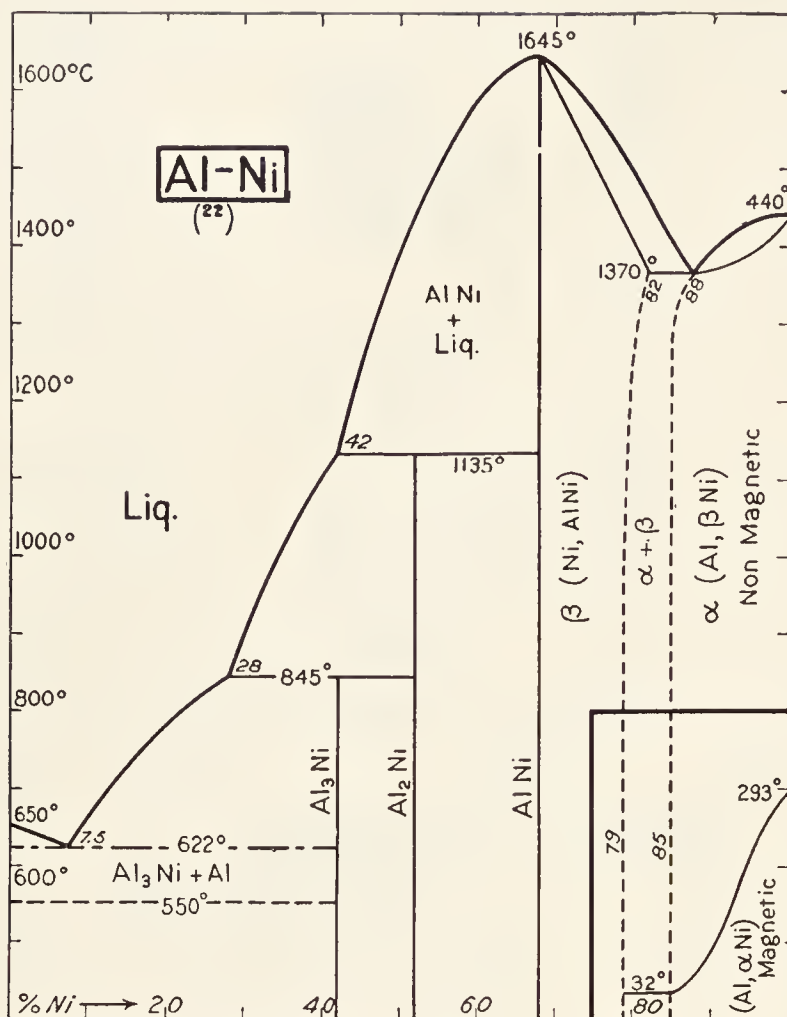


*See* p. 609

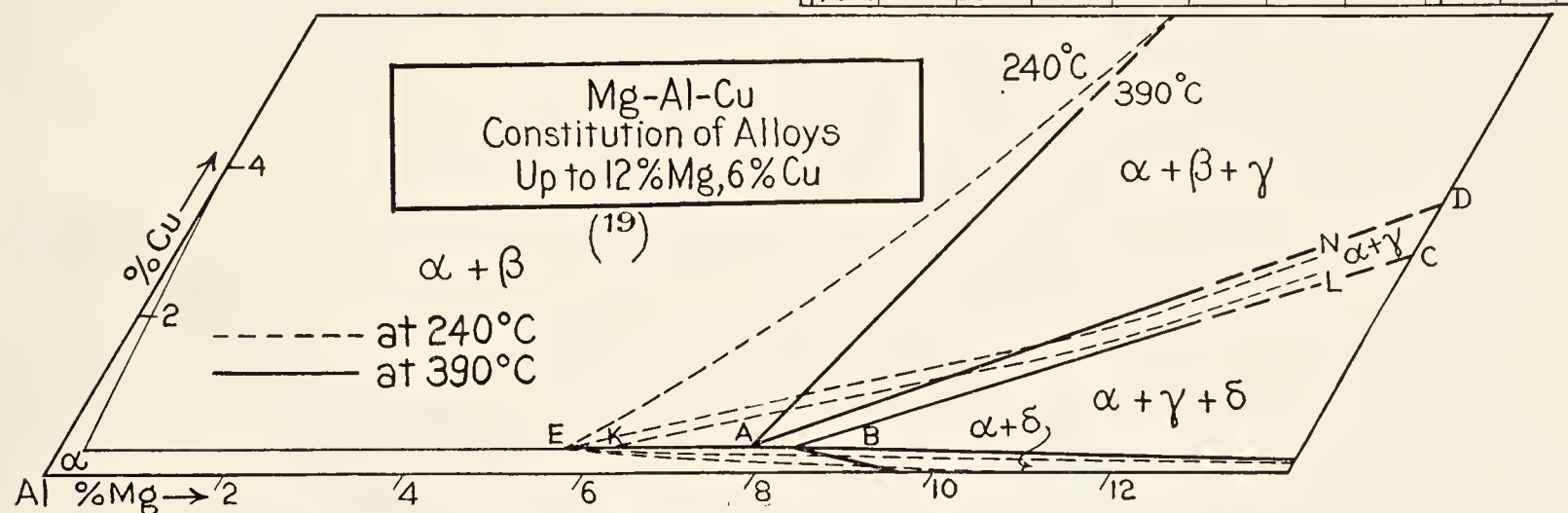
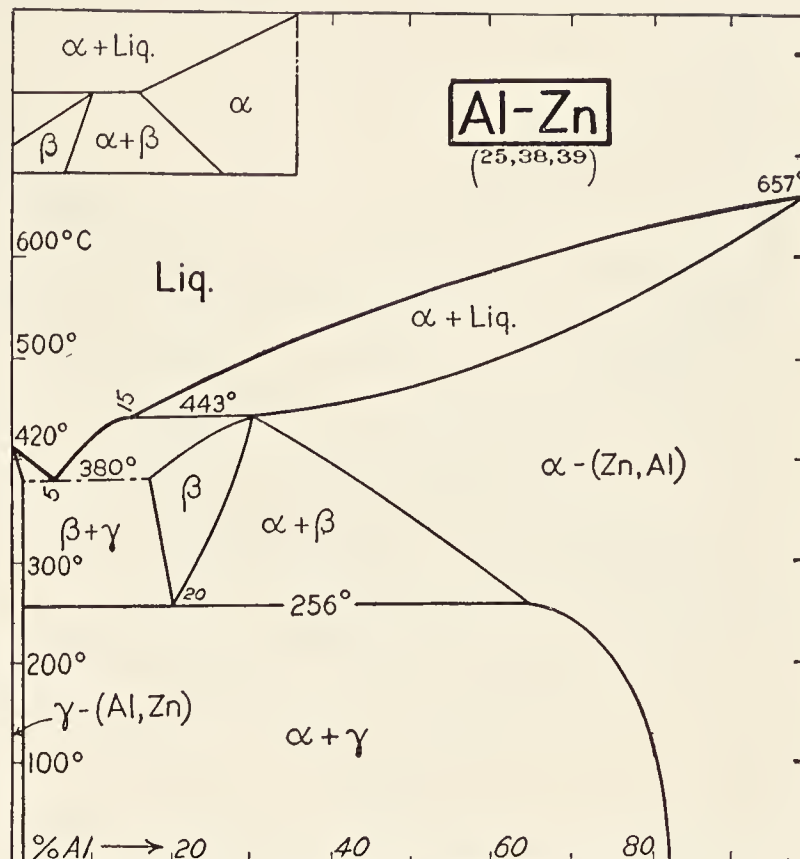
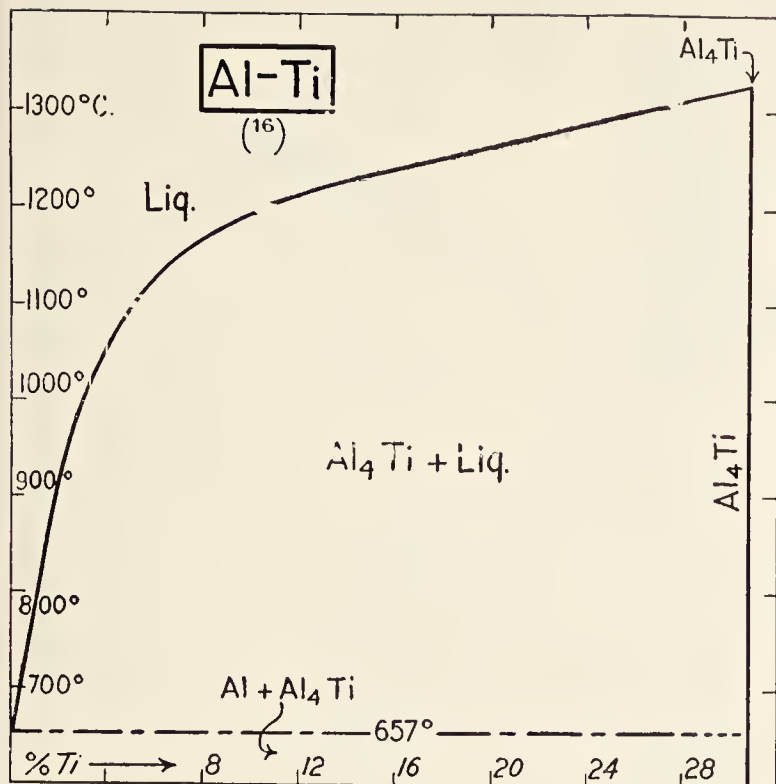






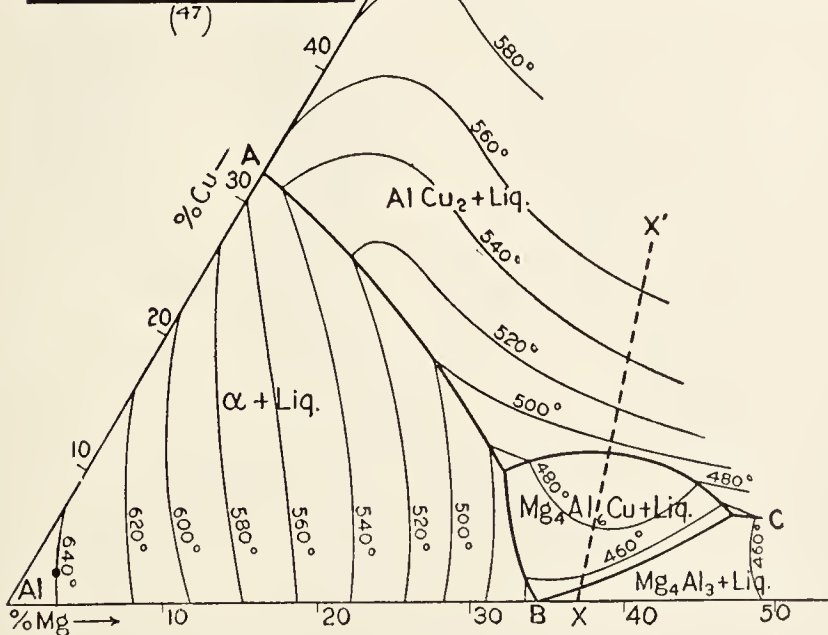




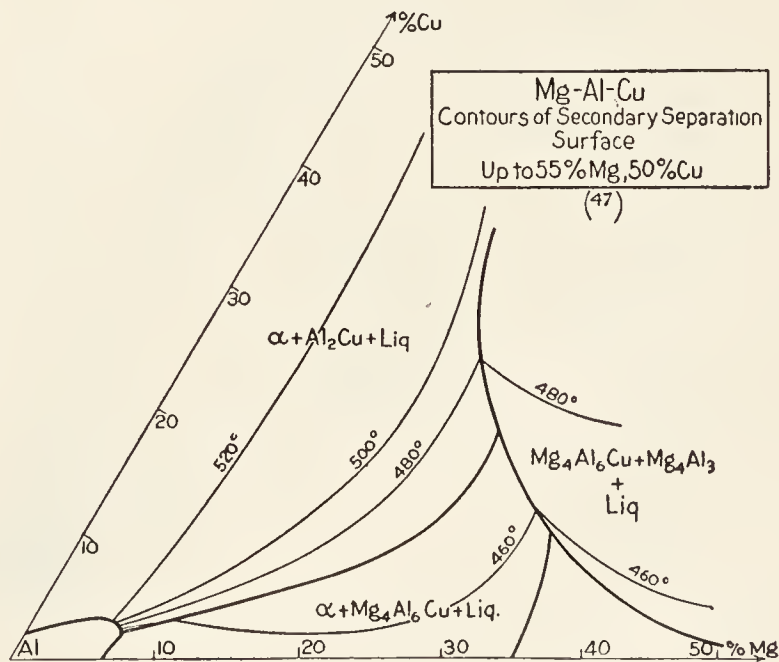


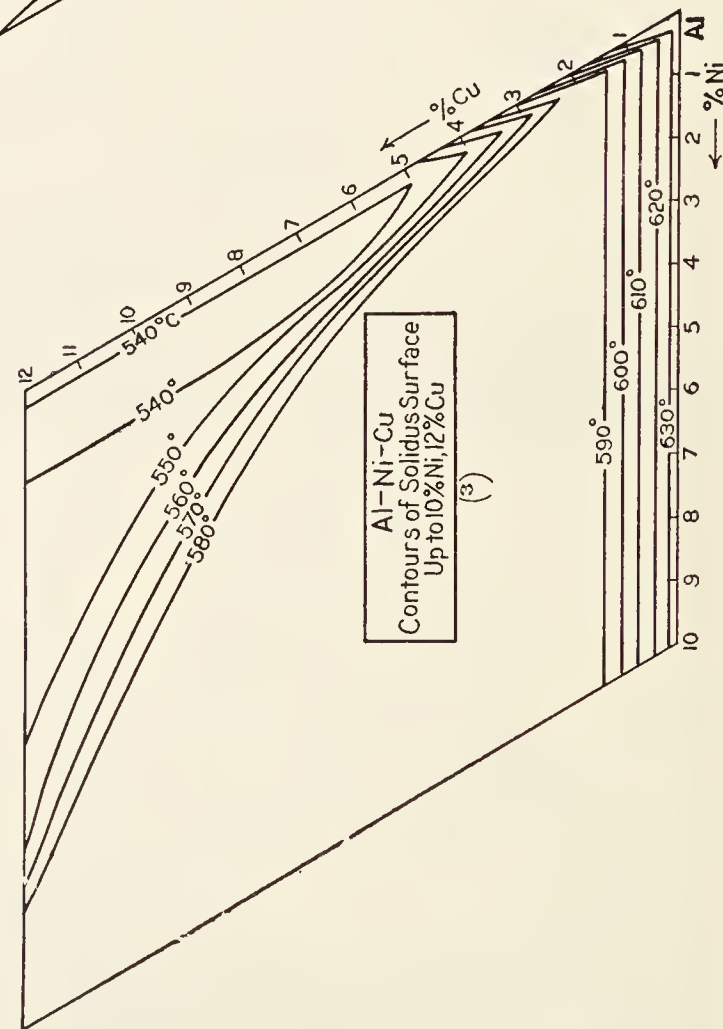
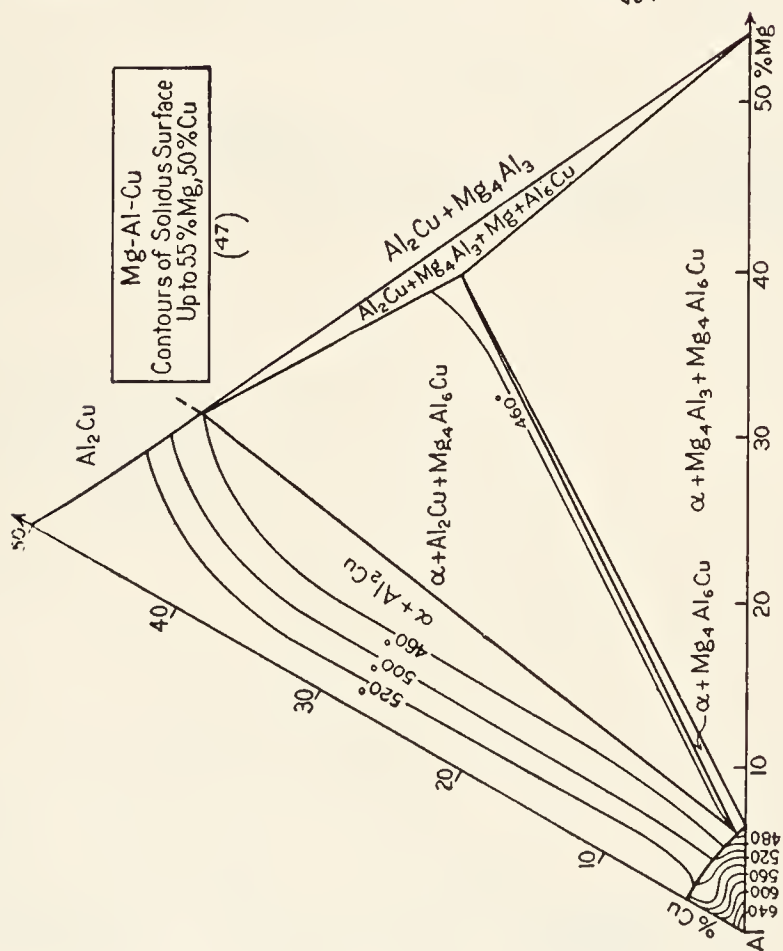
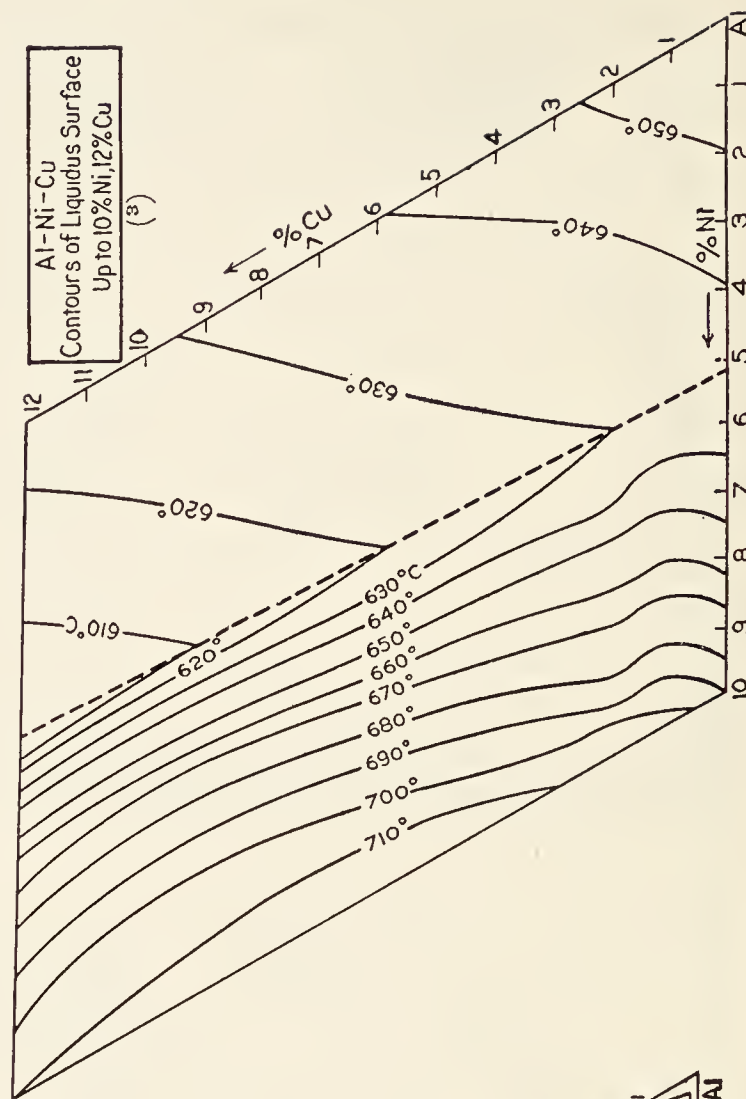
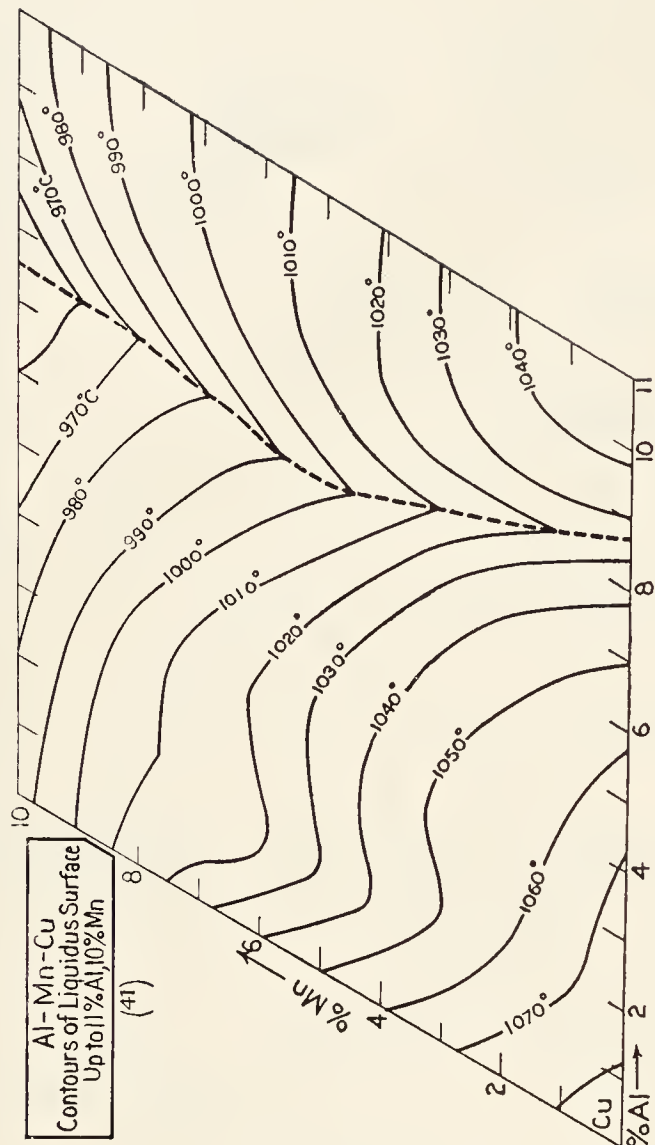
**Mg-Al-Cu**  
Contours of Liquidus Surface  
Up to 55% Mg, 50% Cu  
(47)

Note: The latest work on the system Mg-Al does not confirm the existence of  $\text{Mg}_4\text{Al}_3$ .

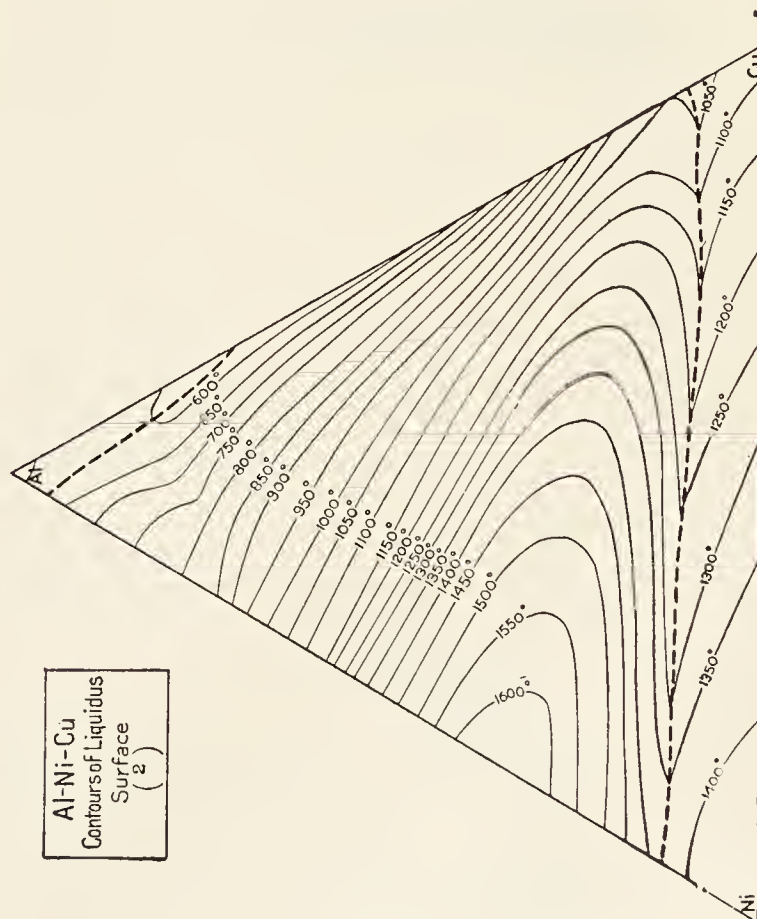
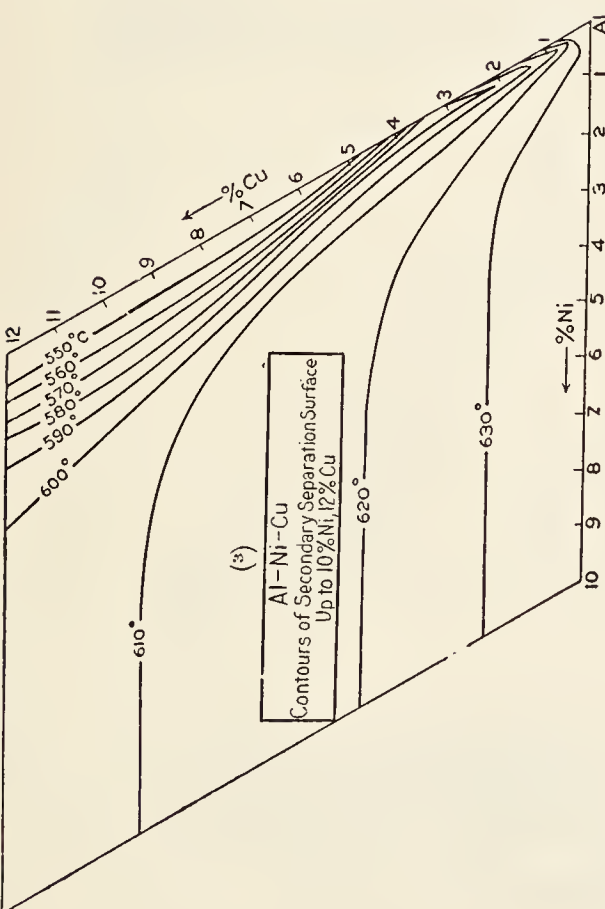
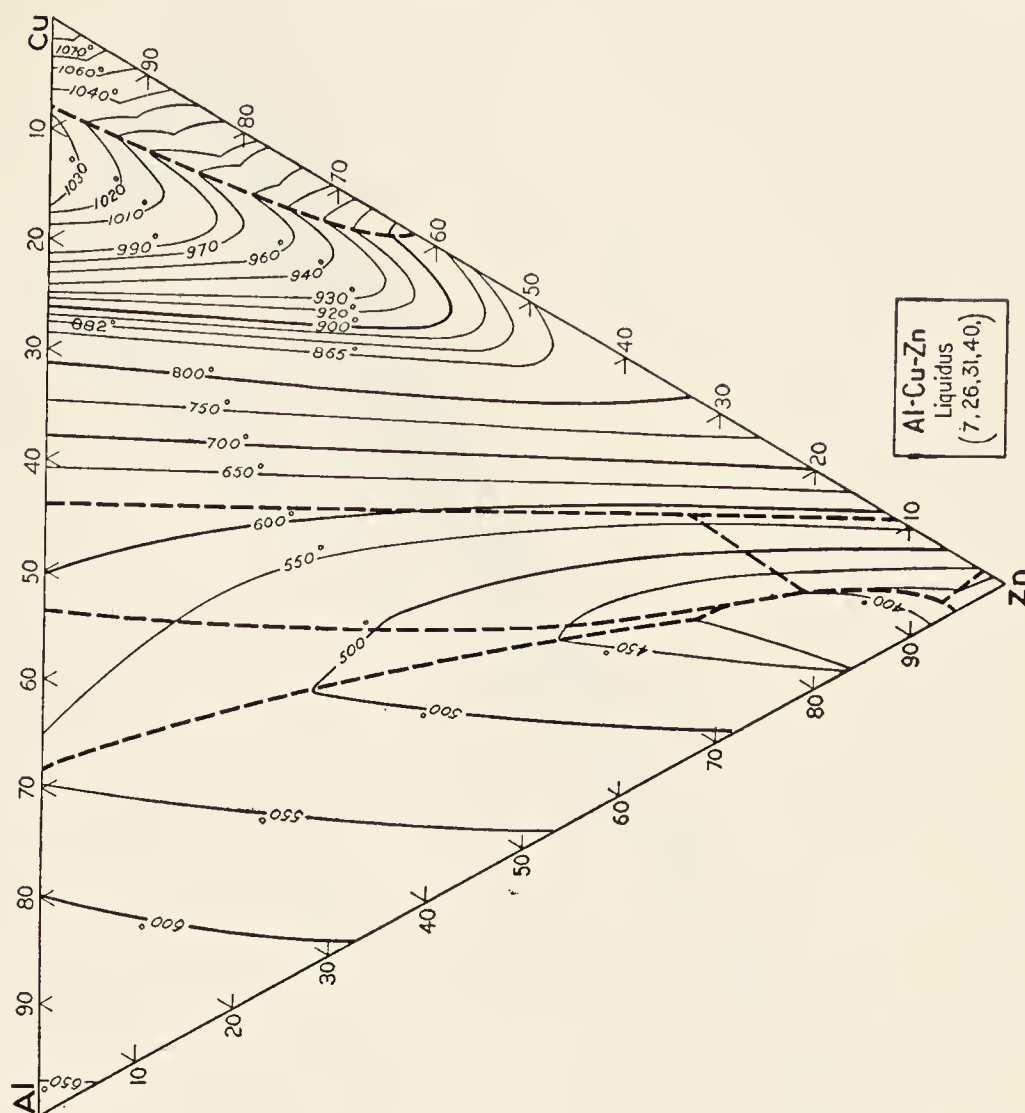
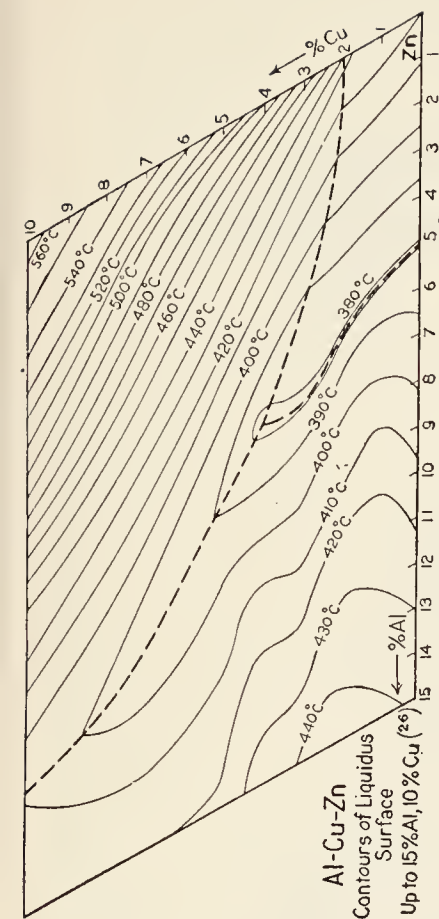


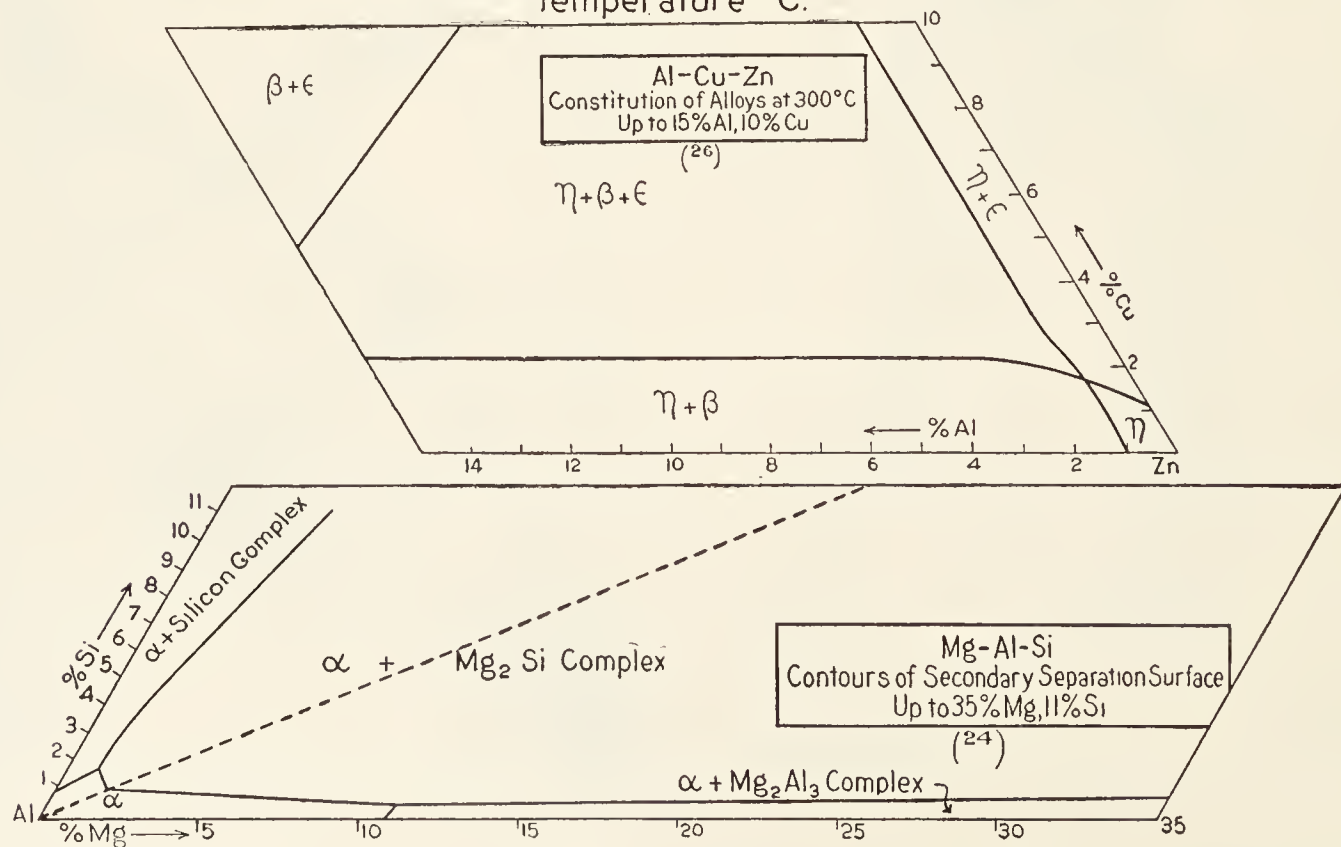
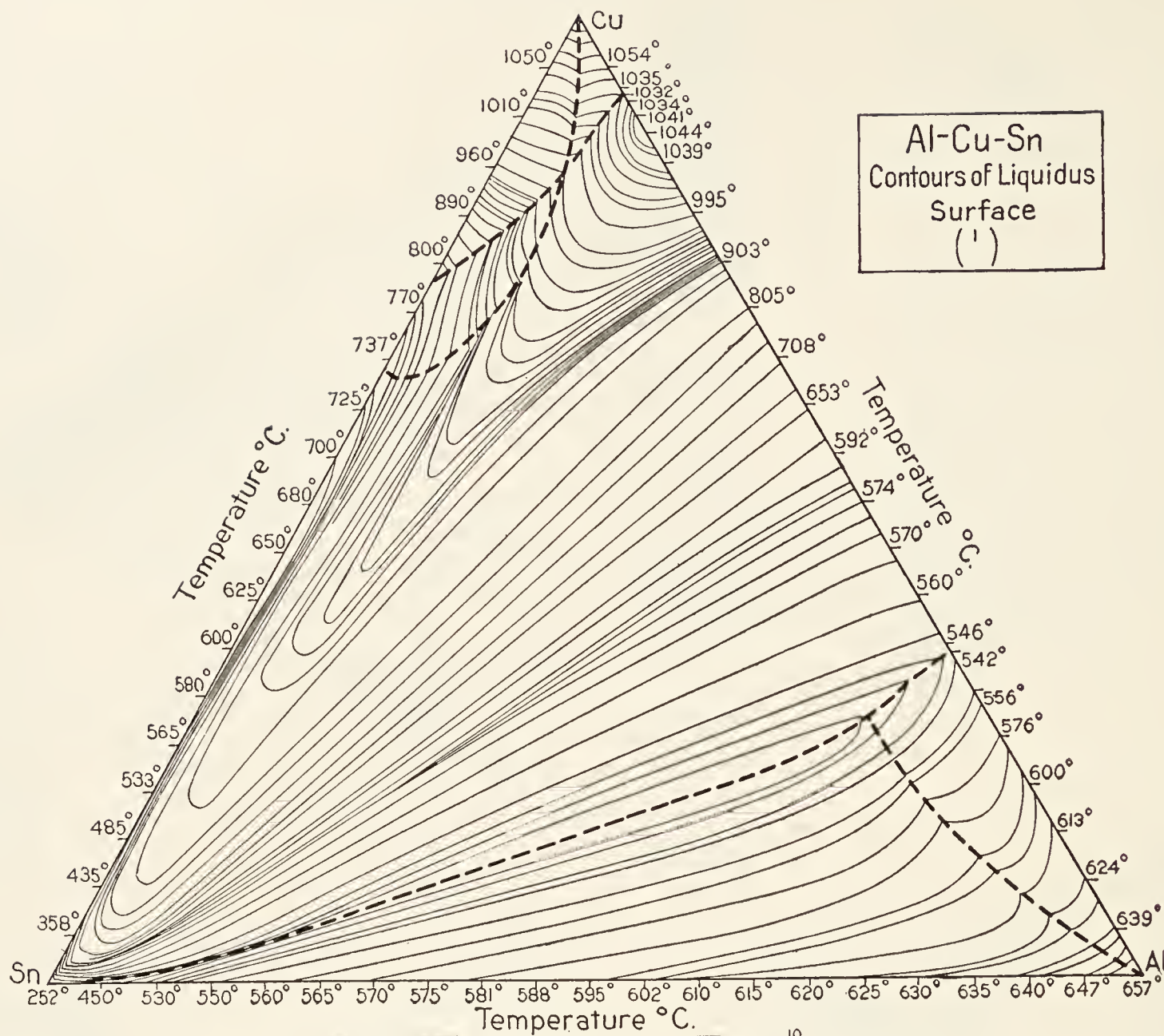
**Mg-Al-Cu**  
Contours of Secondary Separation Surface  
Up to 55% Mg, 50% Cu  
(47)



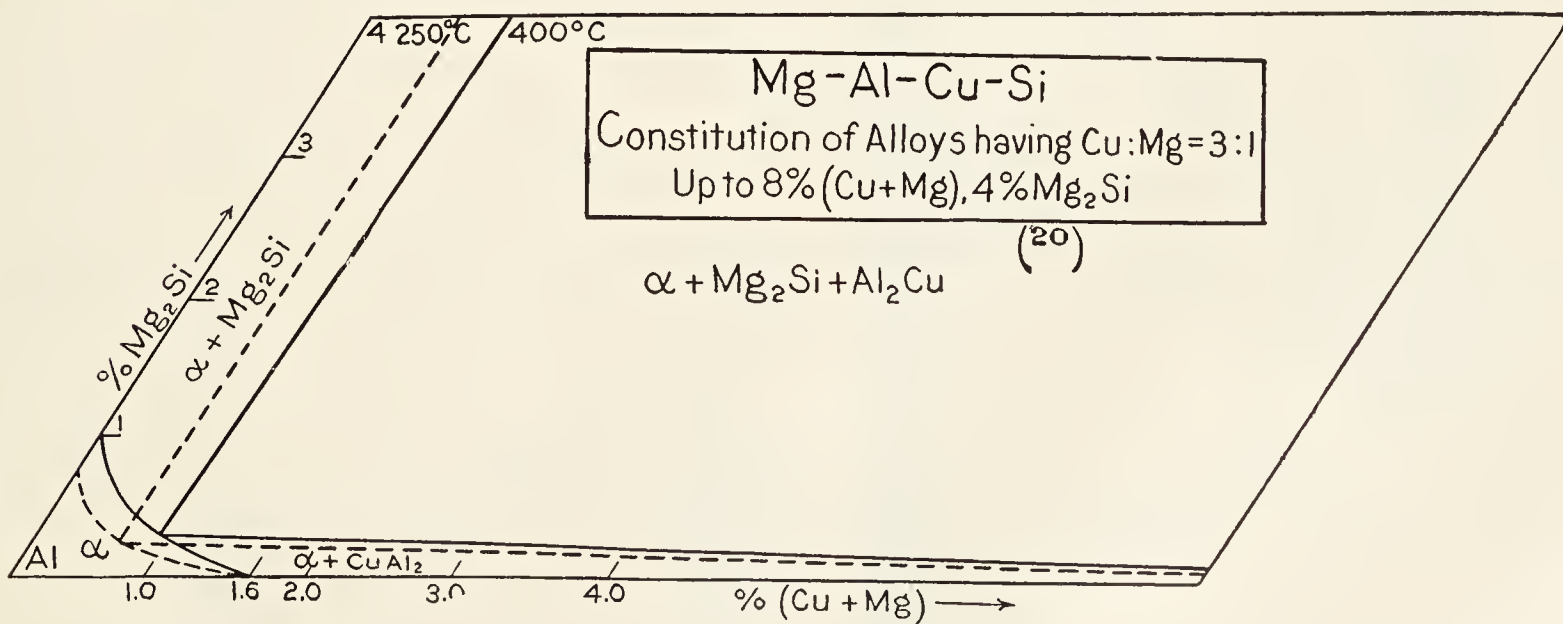
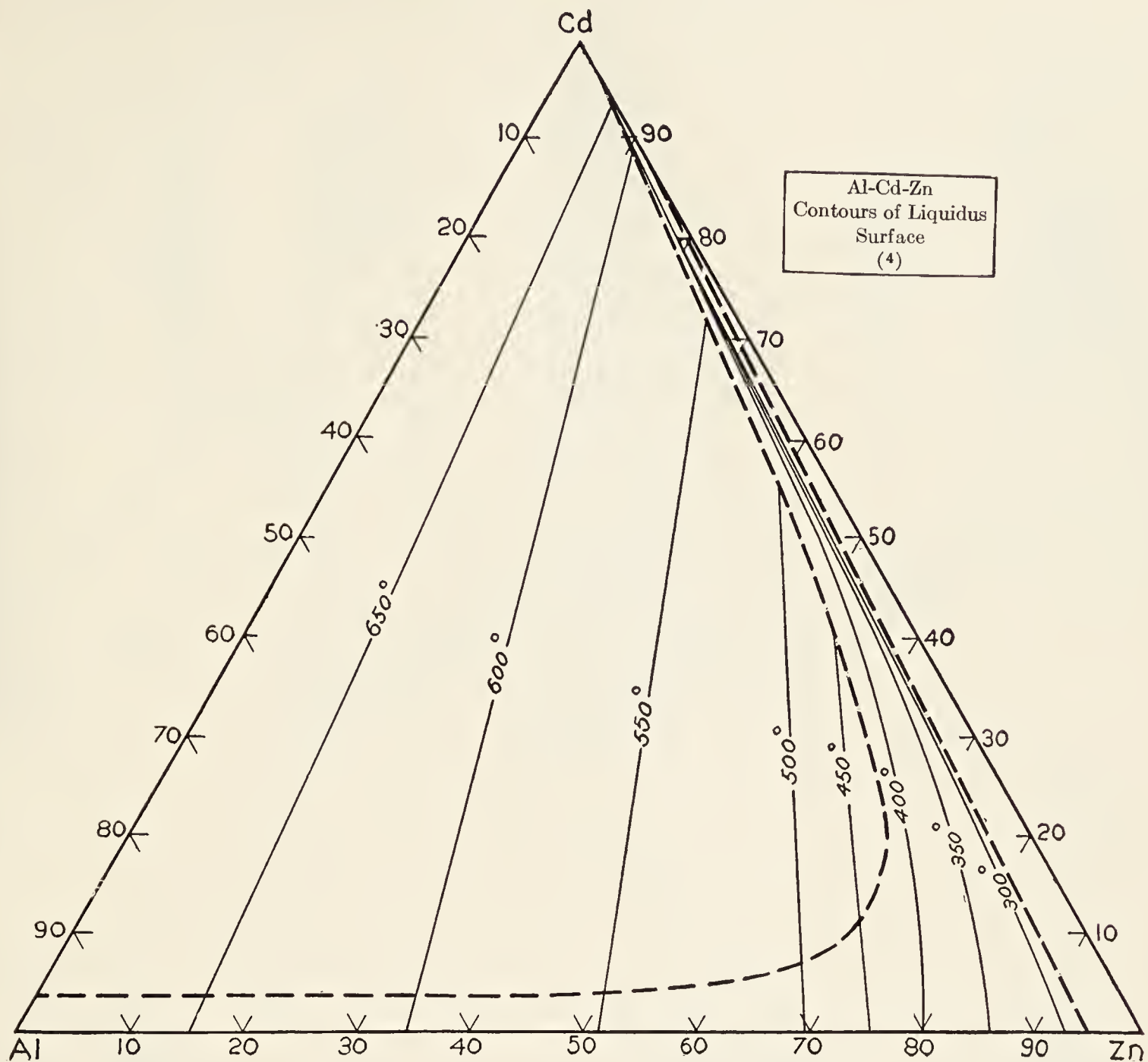


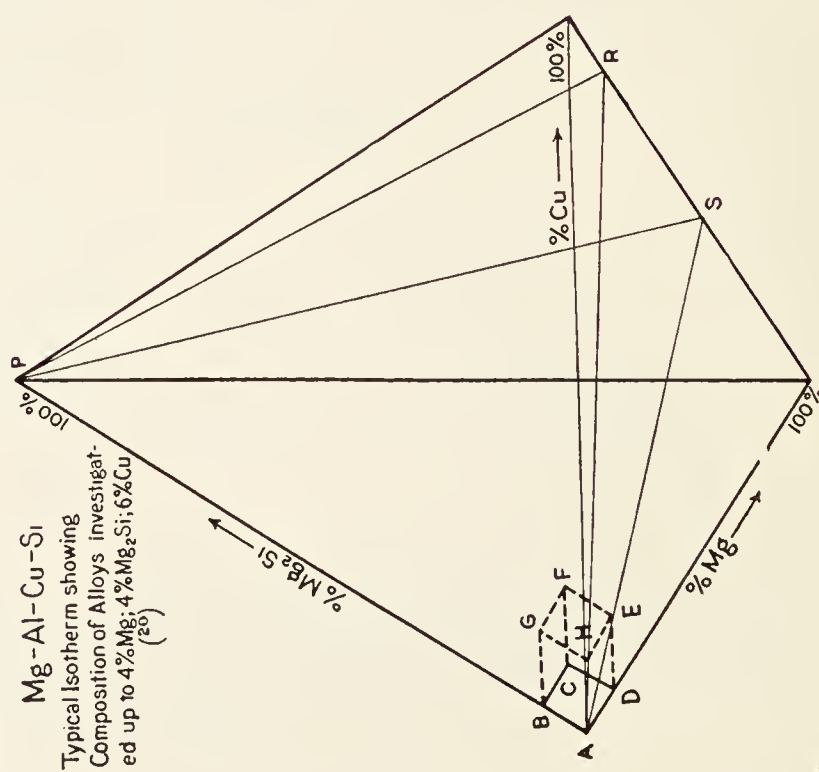
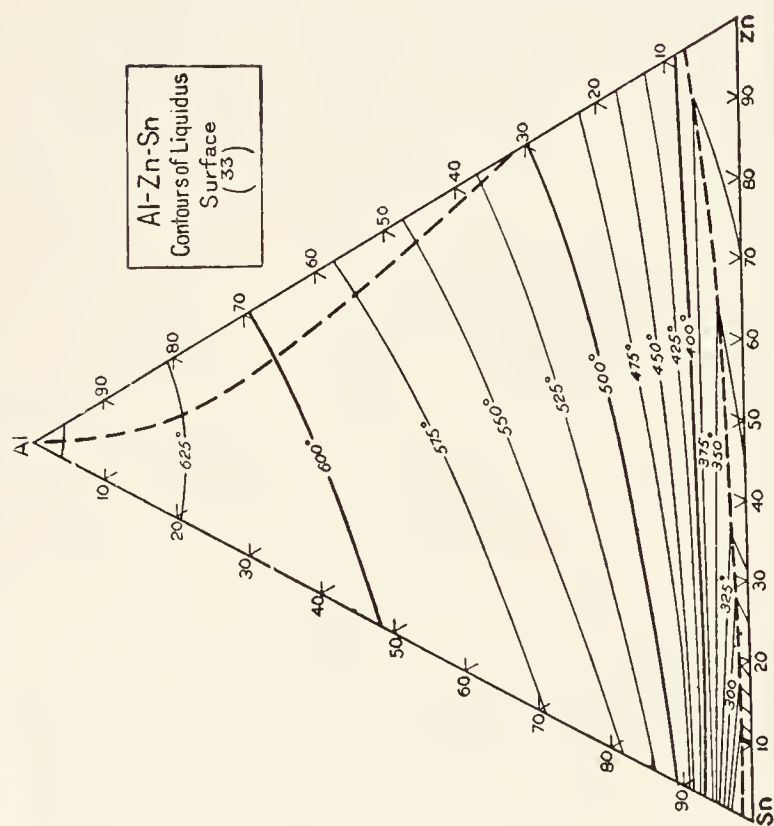
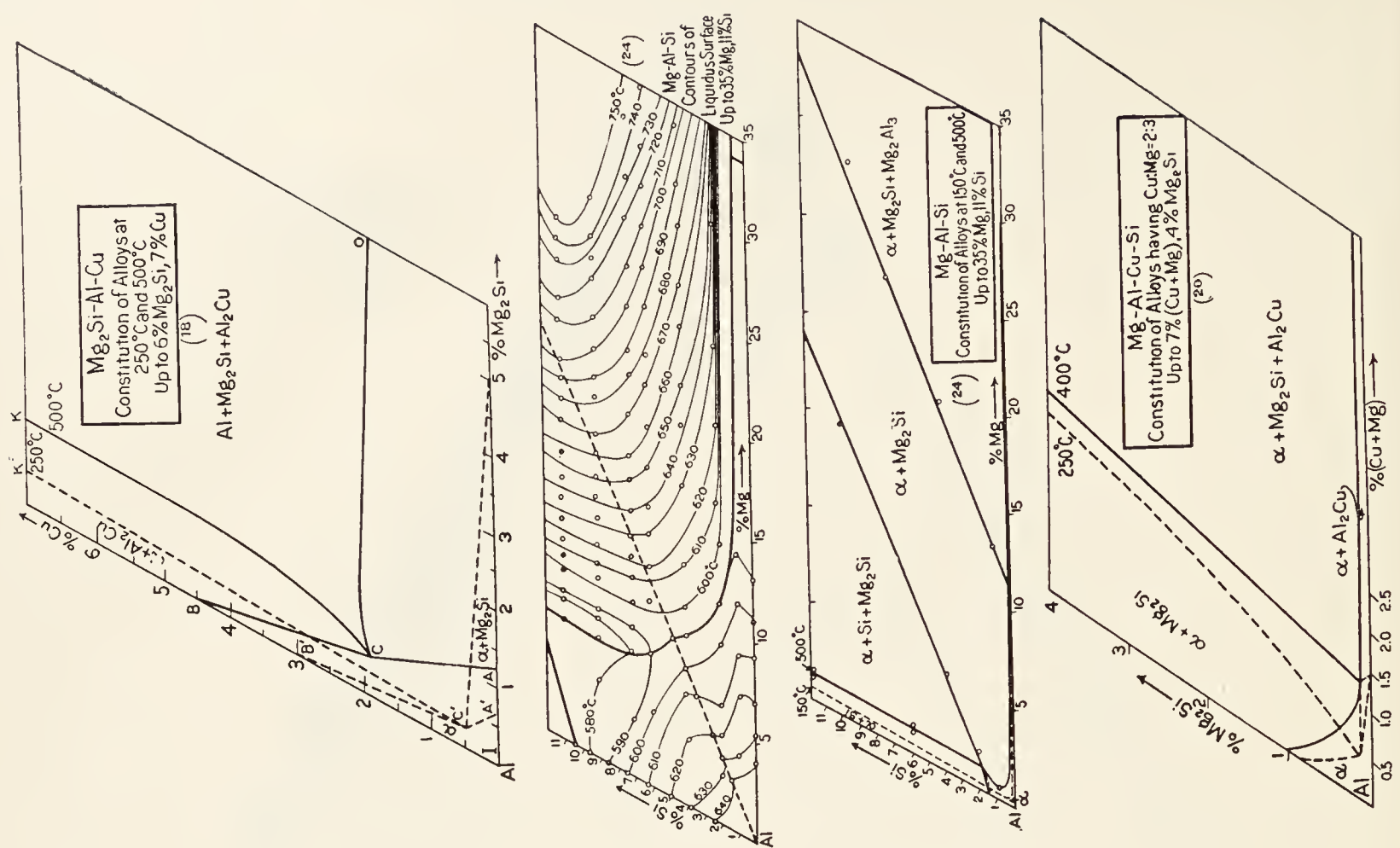




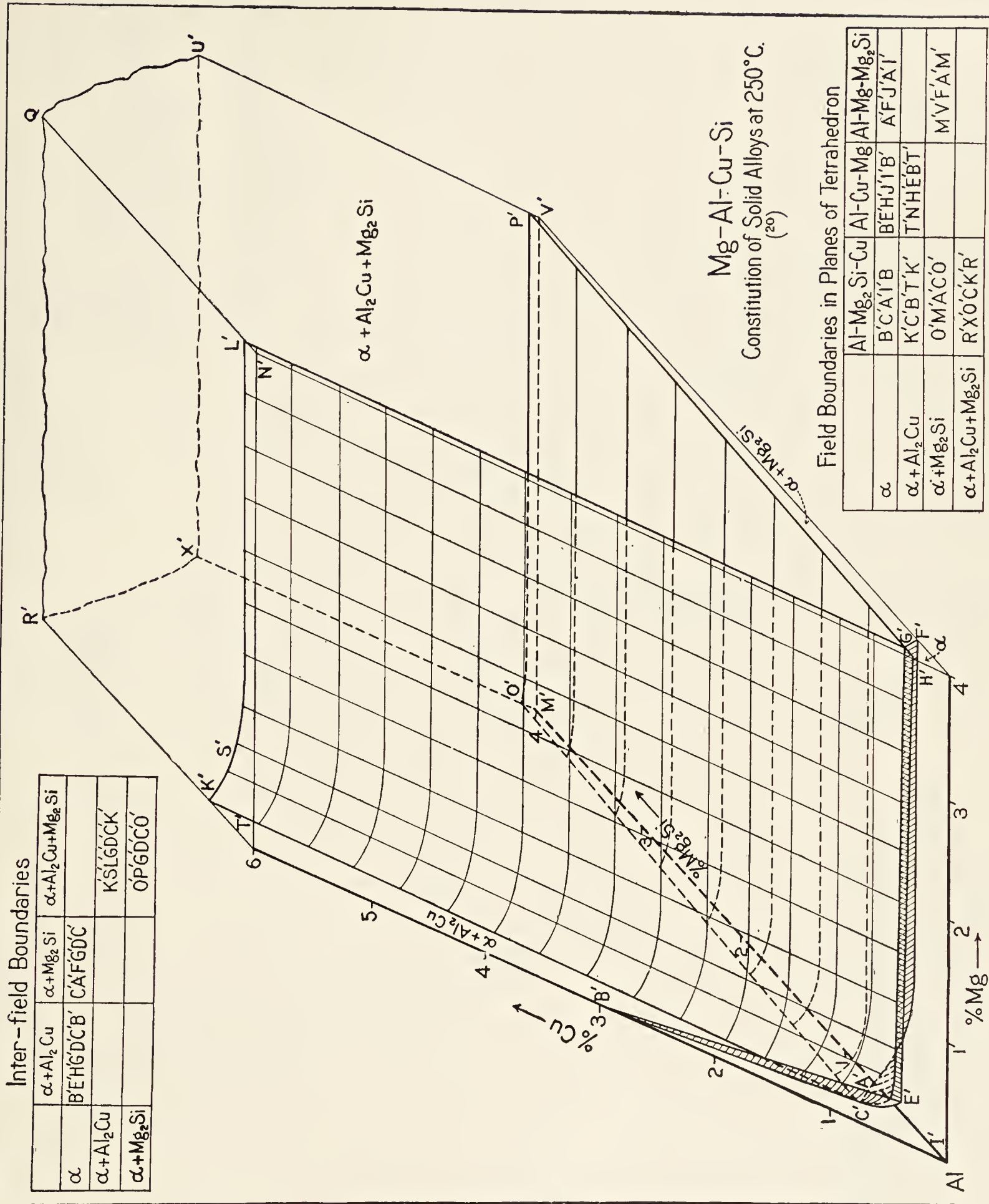




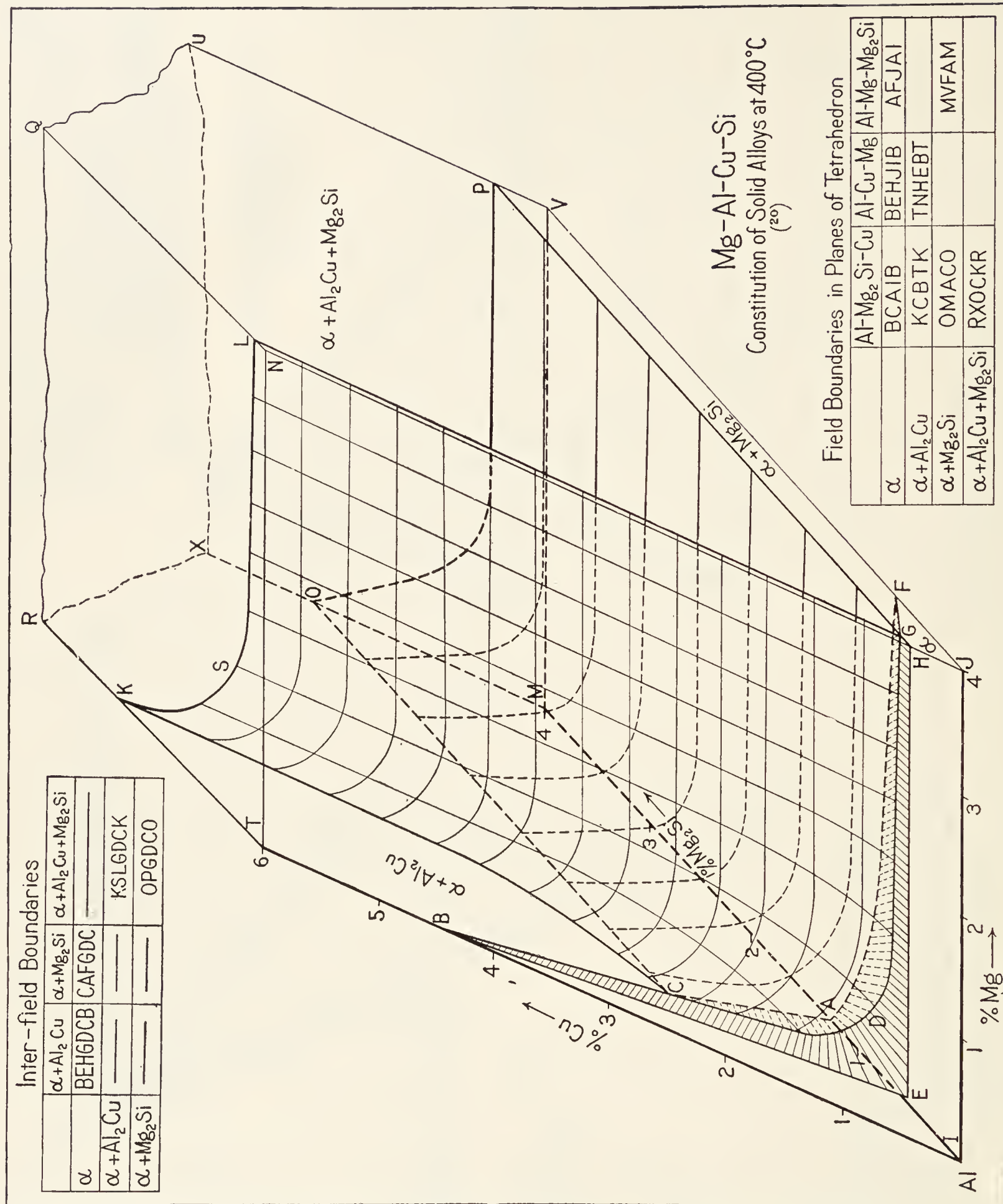








NOTE:—Point J' is at 4% Mg.



NOTE: -Point B should be at 4 % Cu.



## LEAD ALLOYS AND TIN ALLOYS

O. F. HUDSON

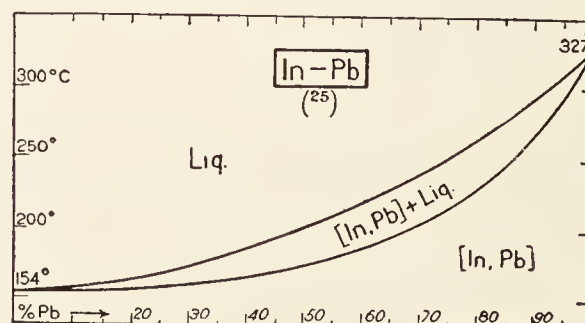
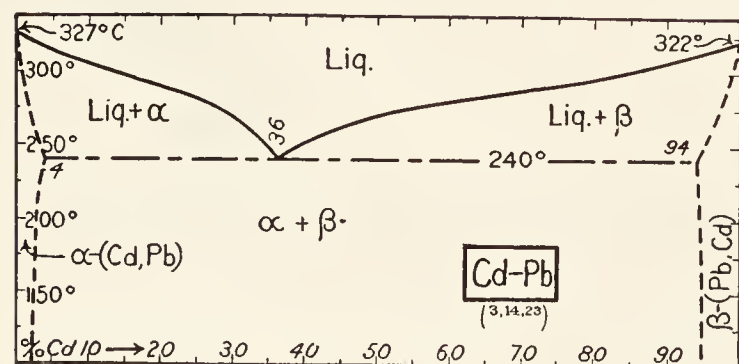
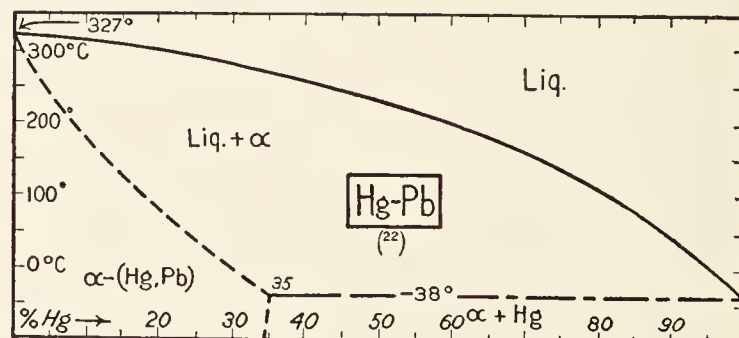
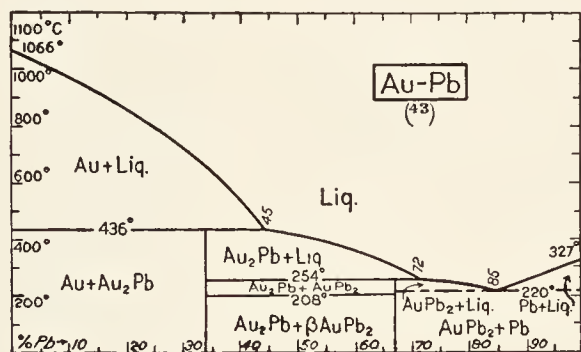
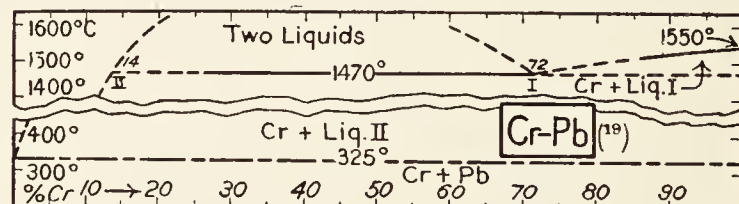
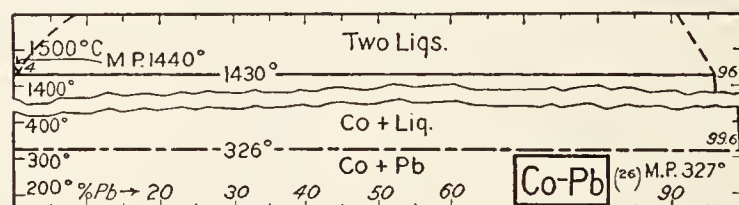
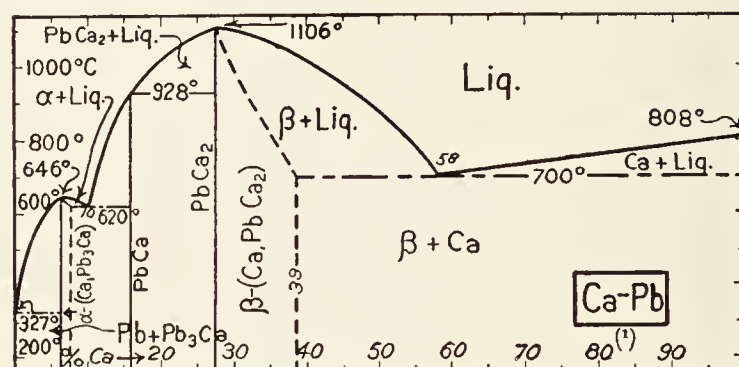
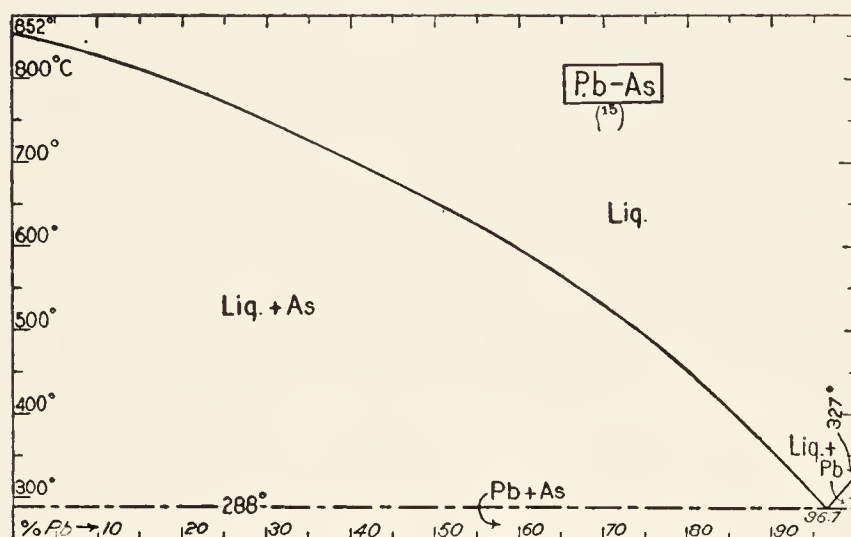
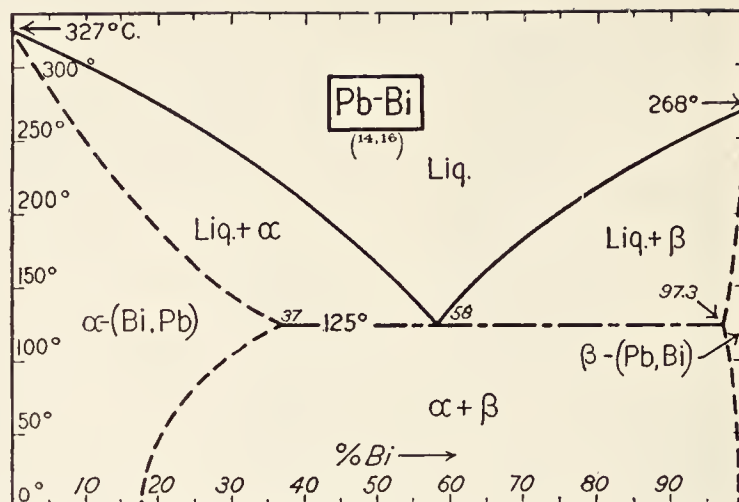
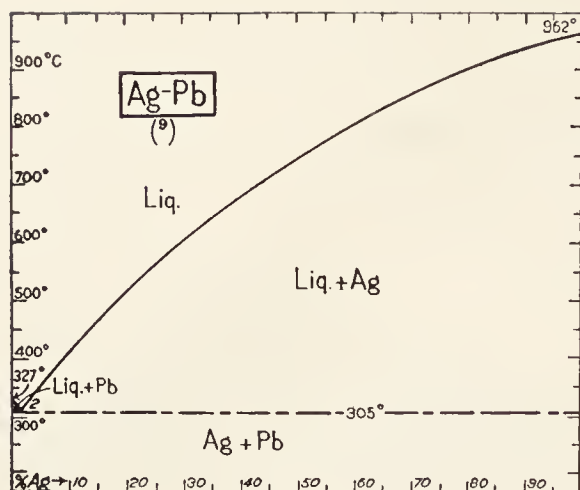
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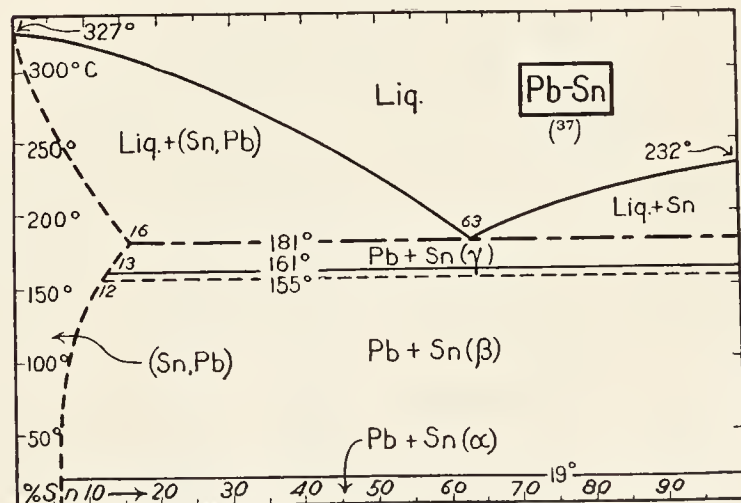
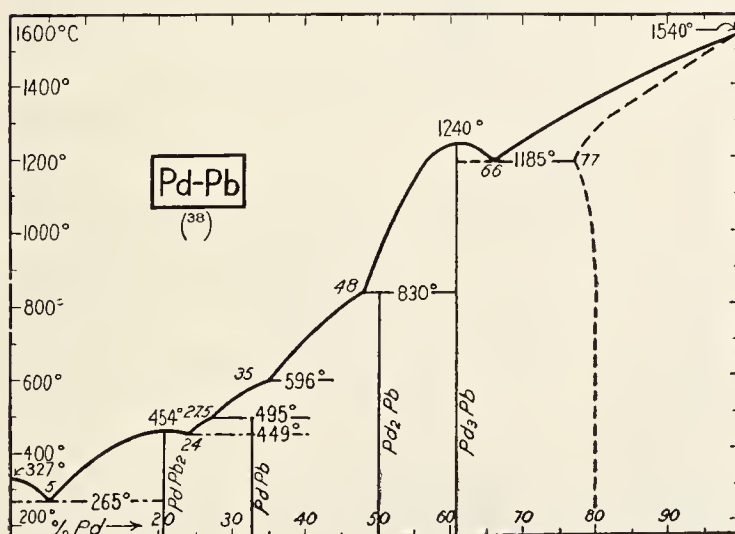
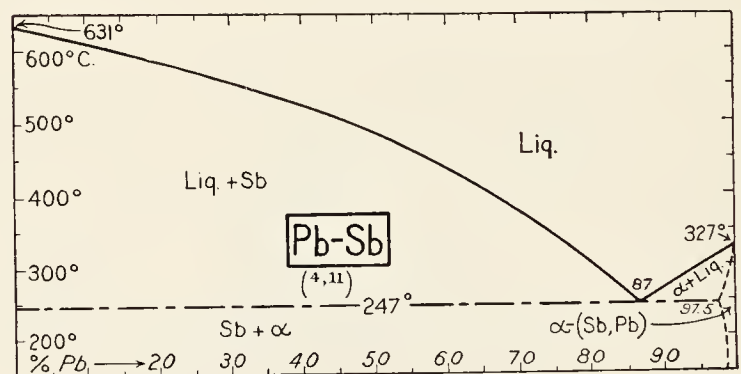
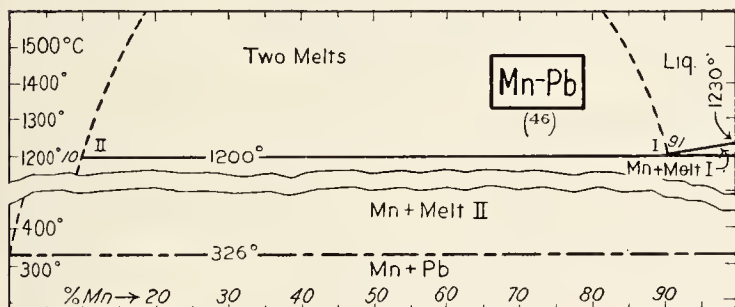
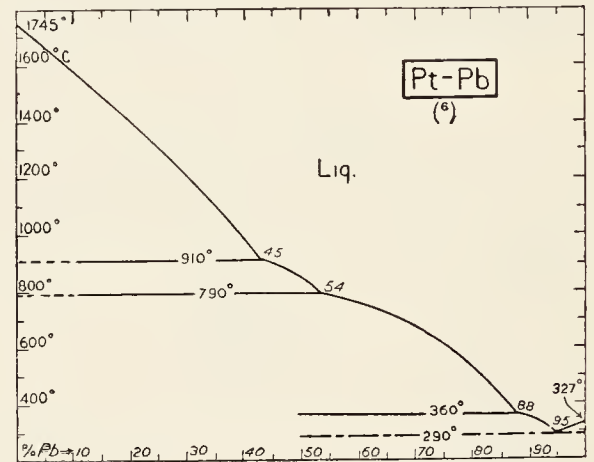
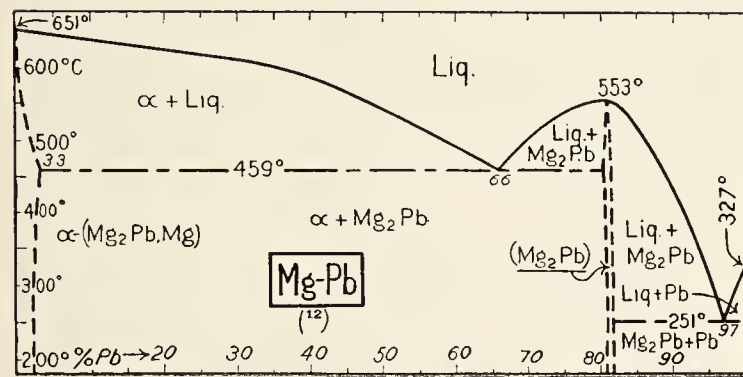
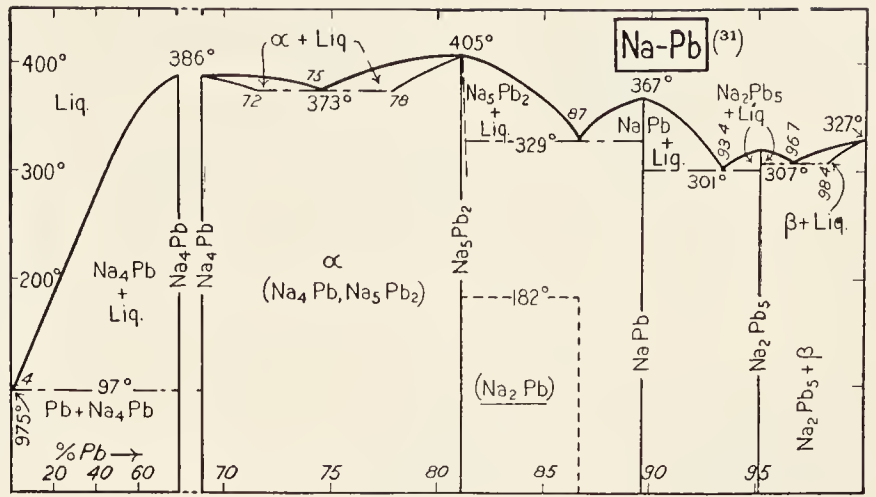
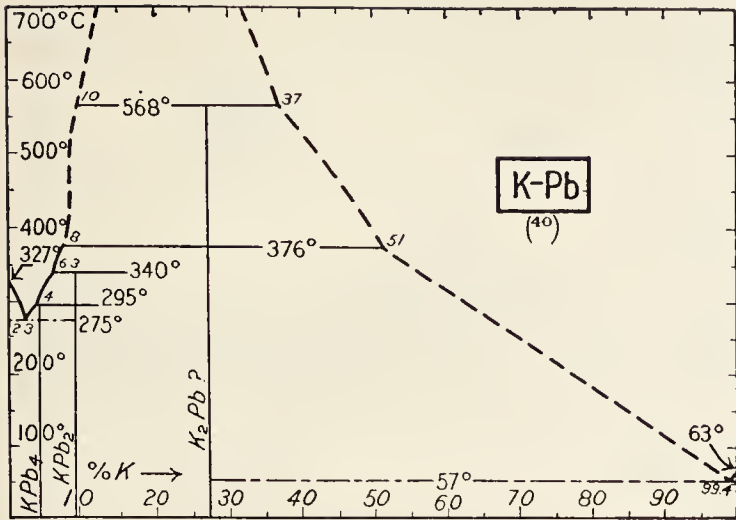
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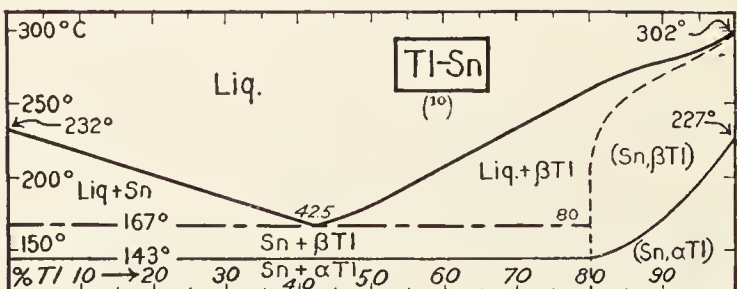
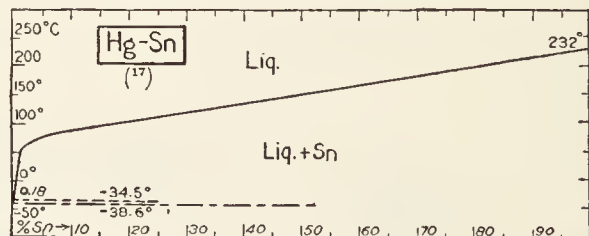
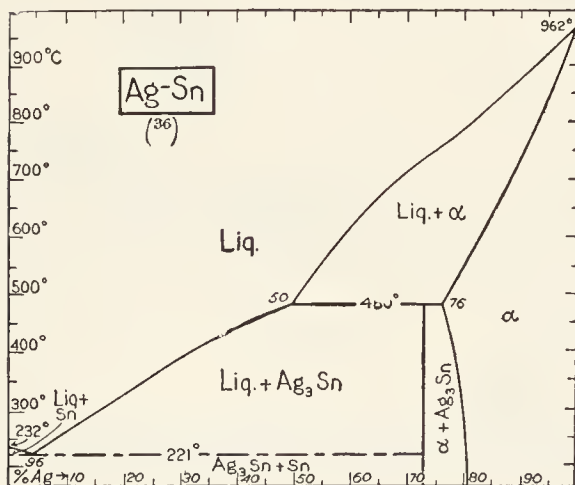
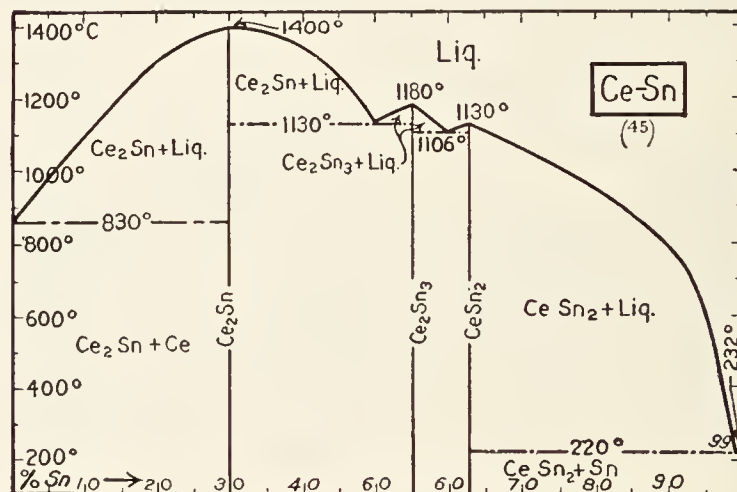
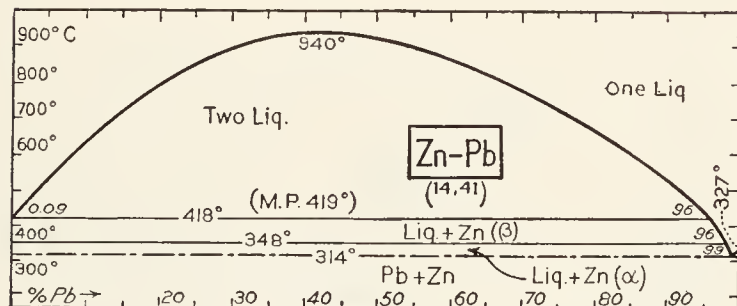
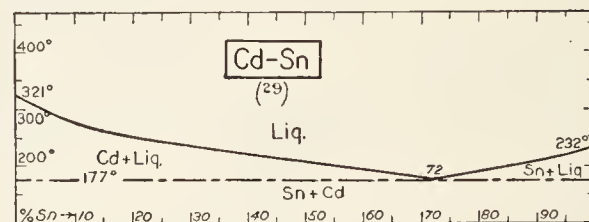
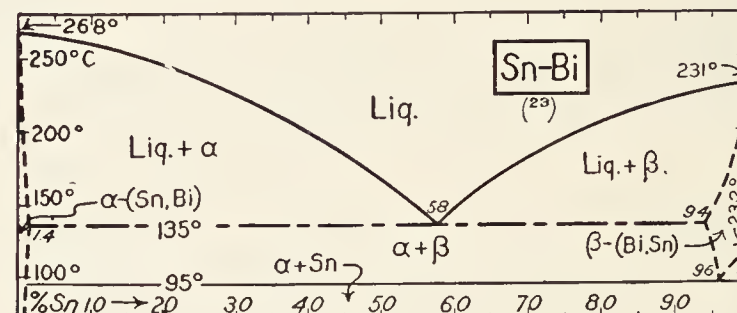
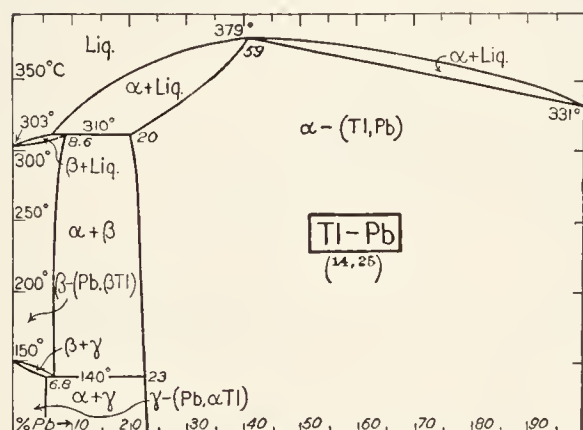
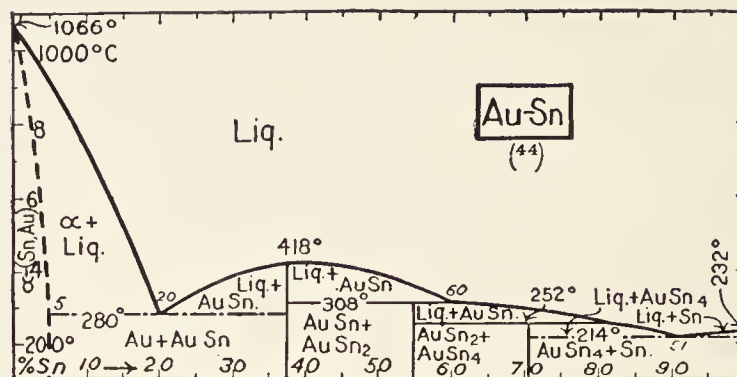
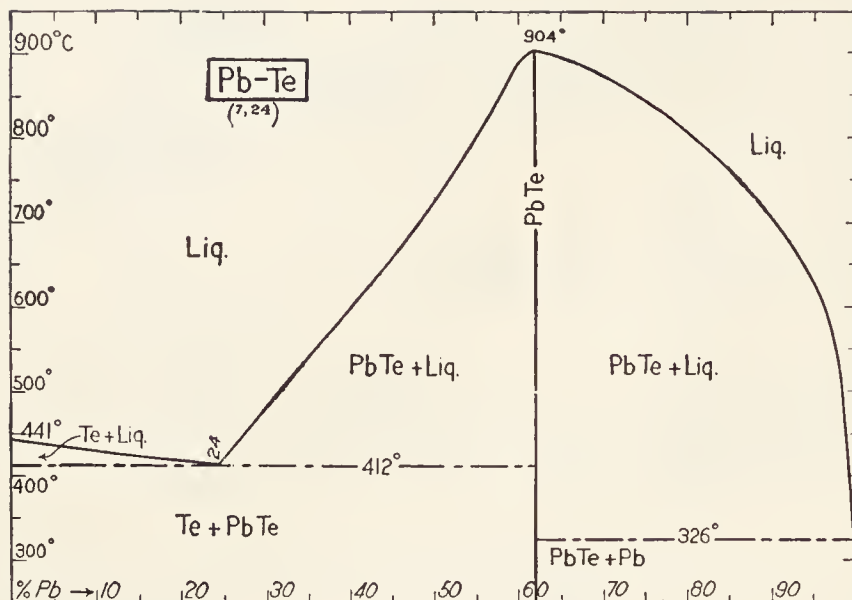
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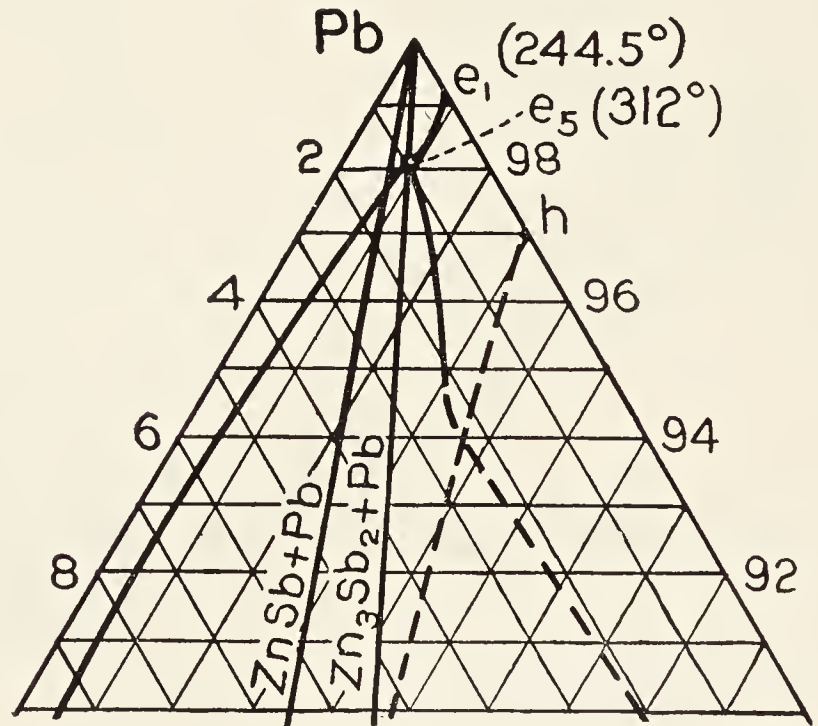
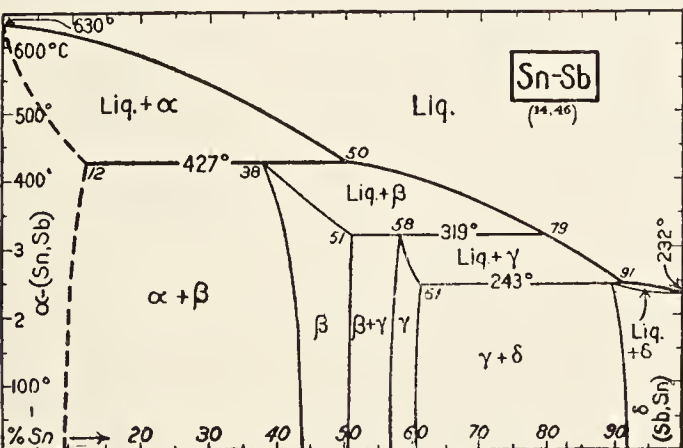
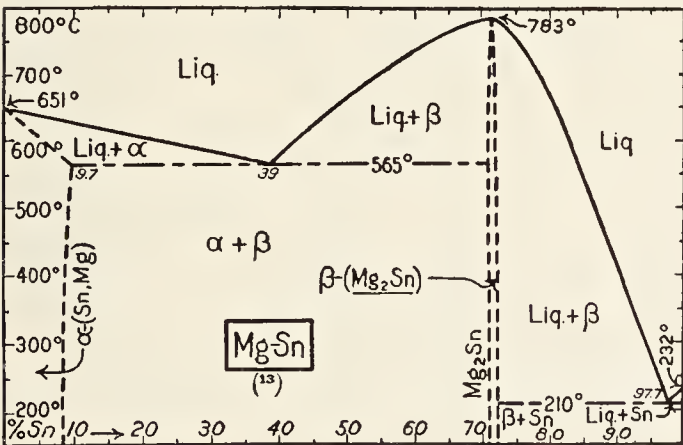
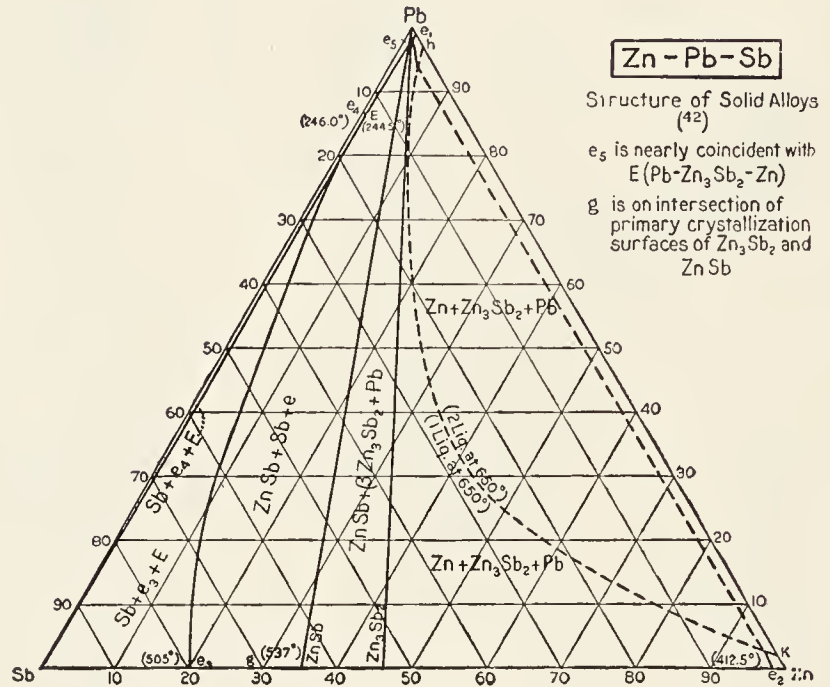
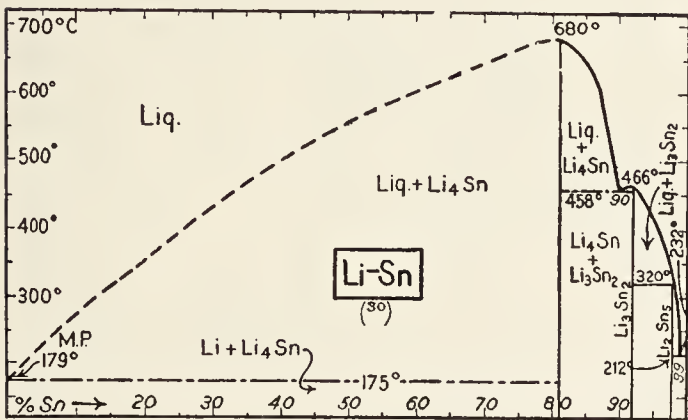
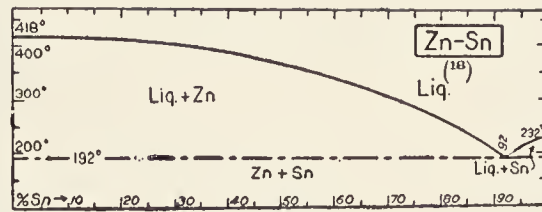
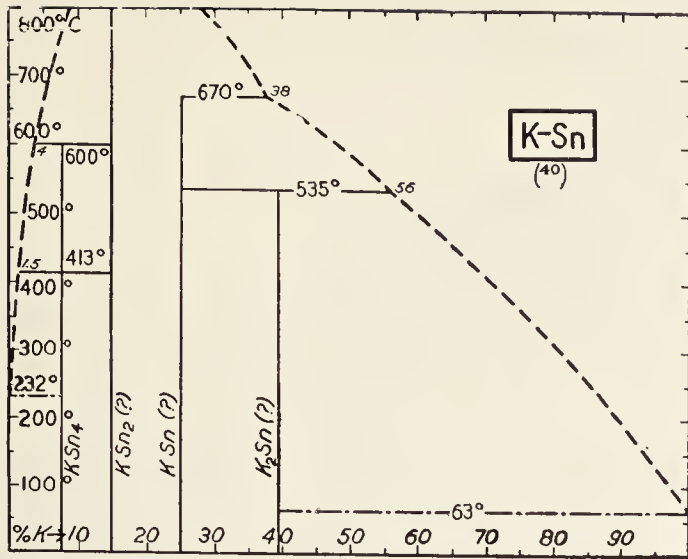


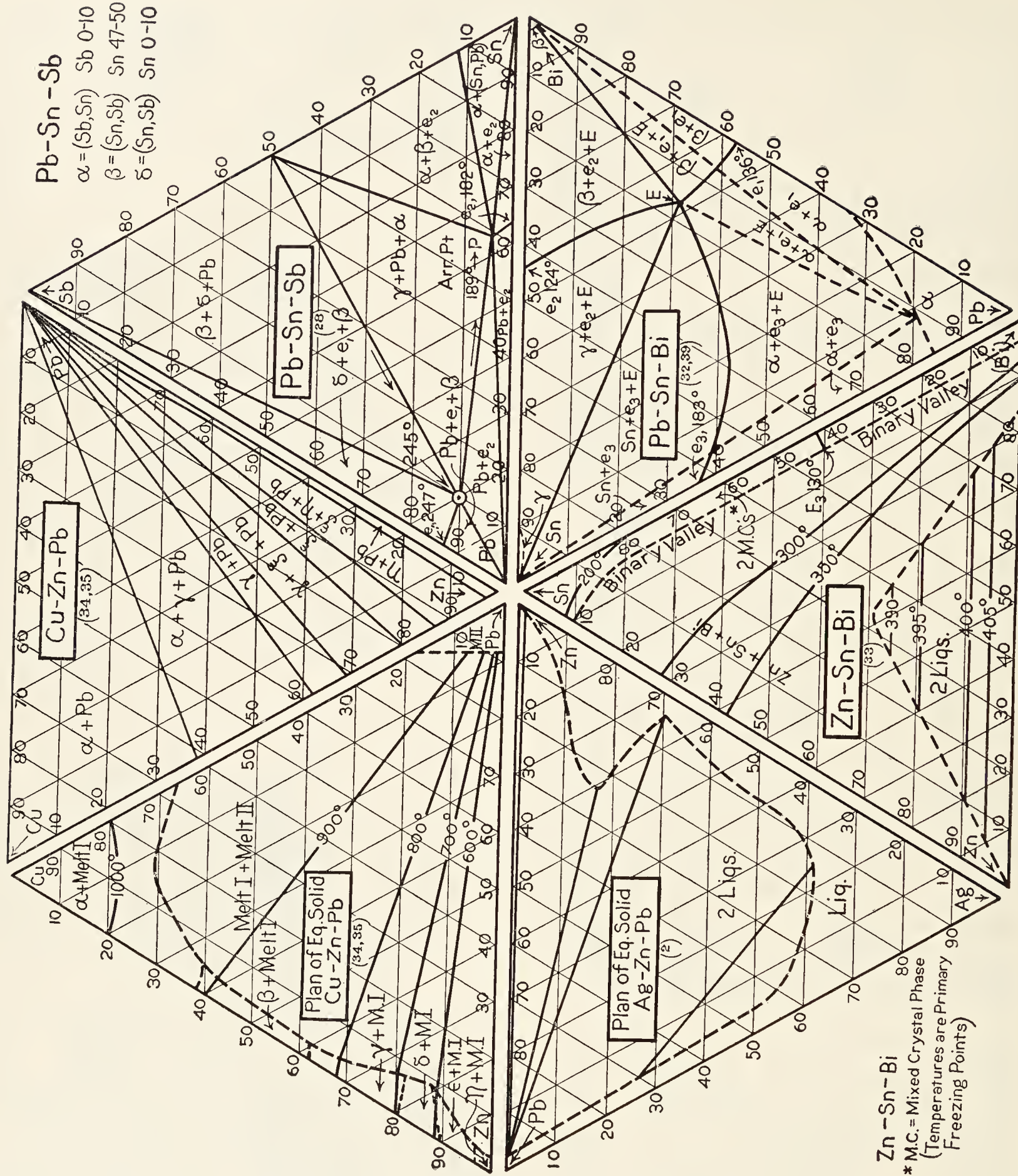














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J. L. HAUGHTON

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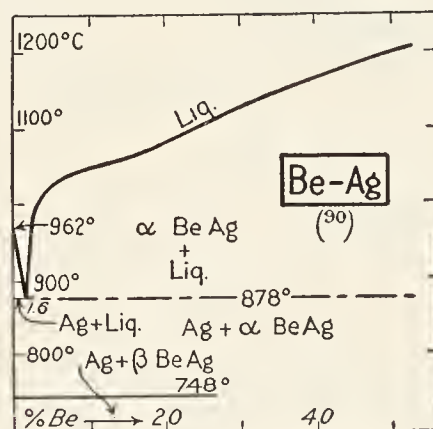
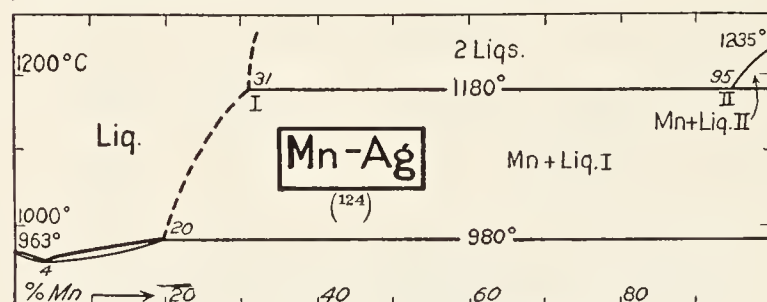
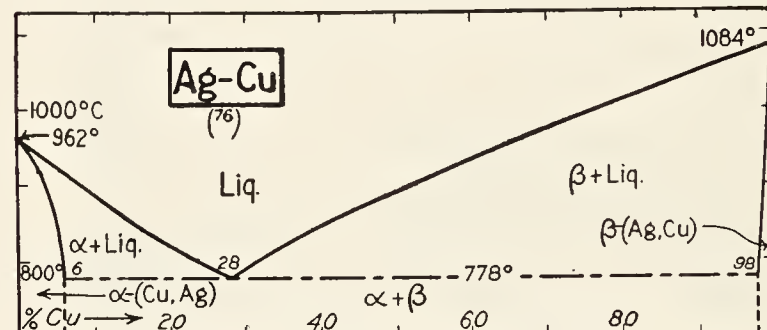
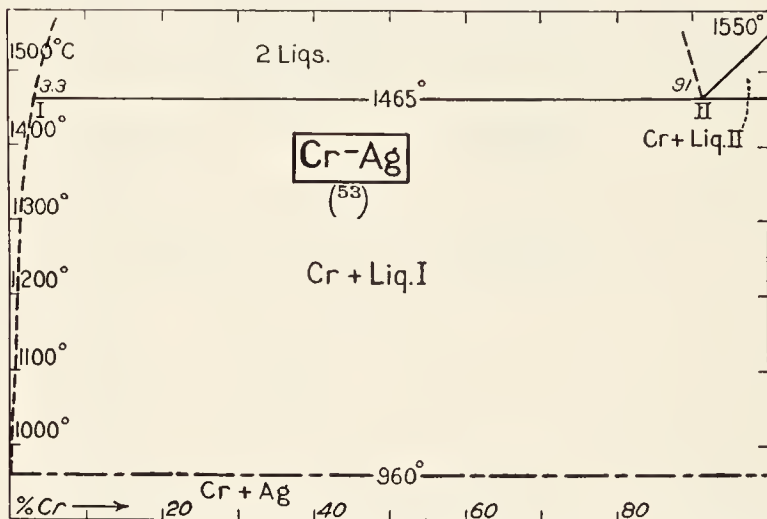
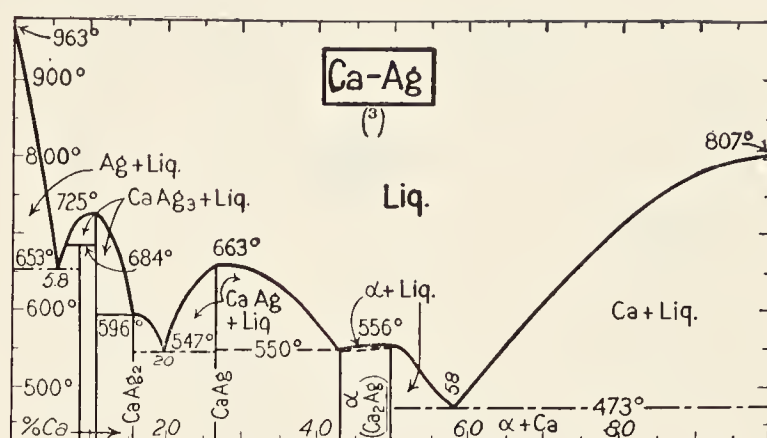
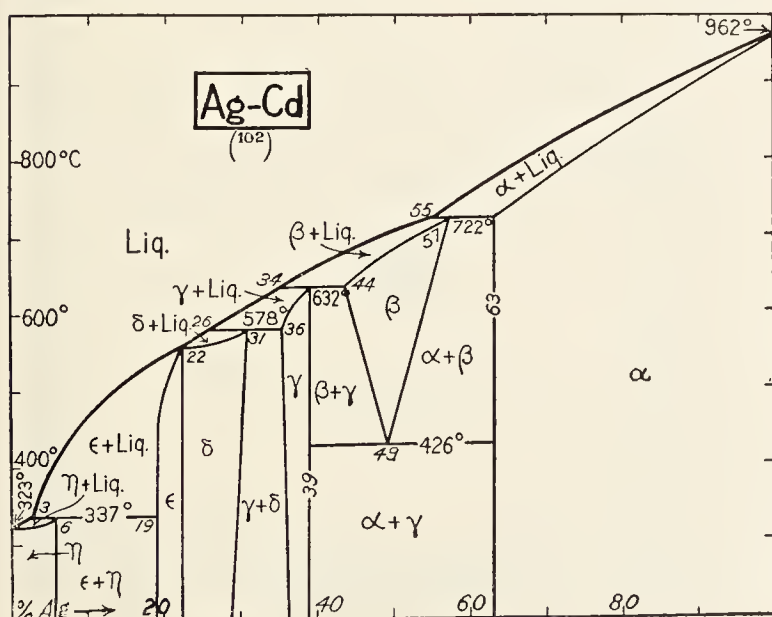
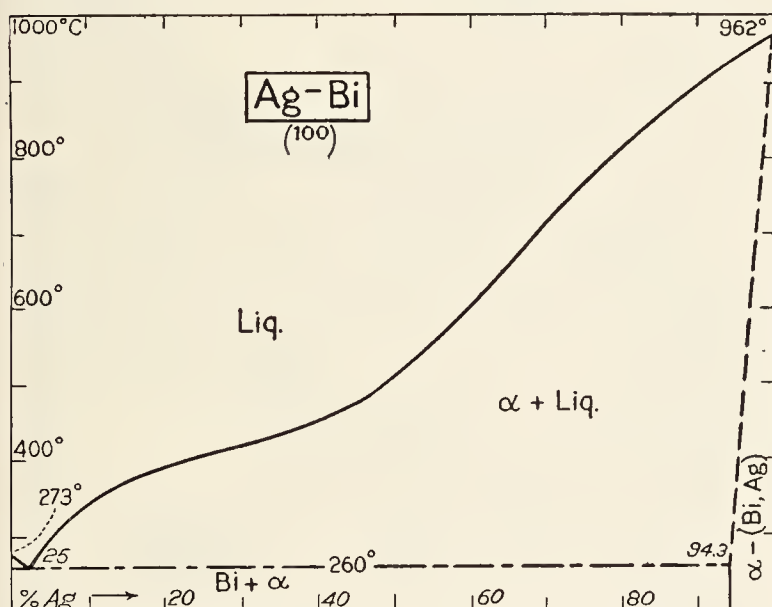
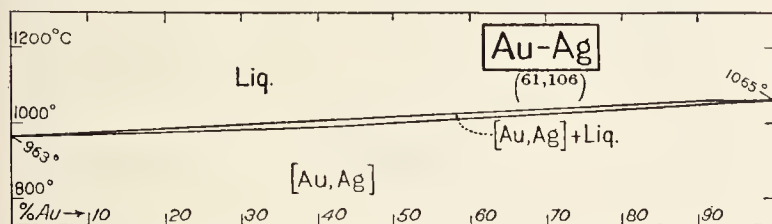
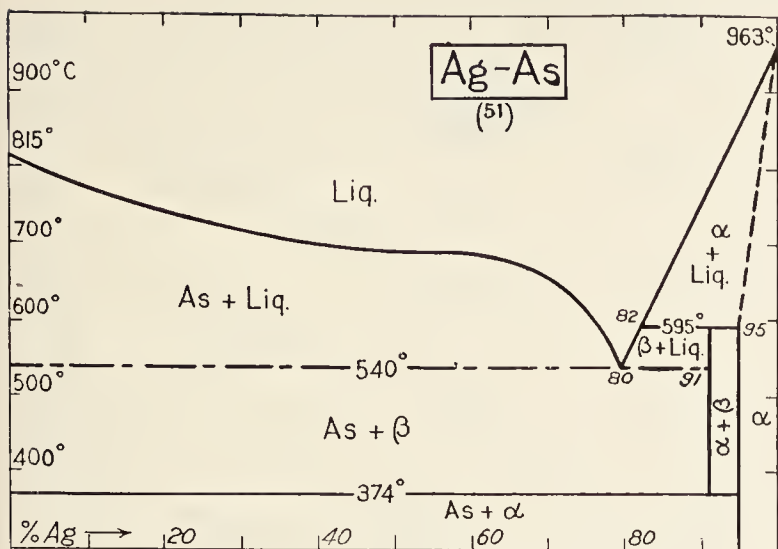
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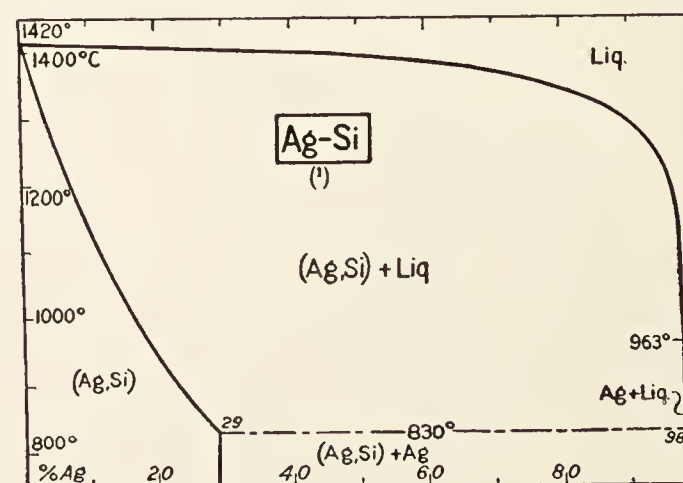
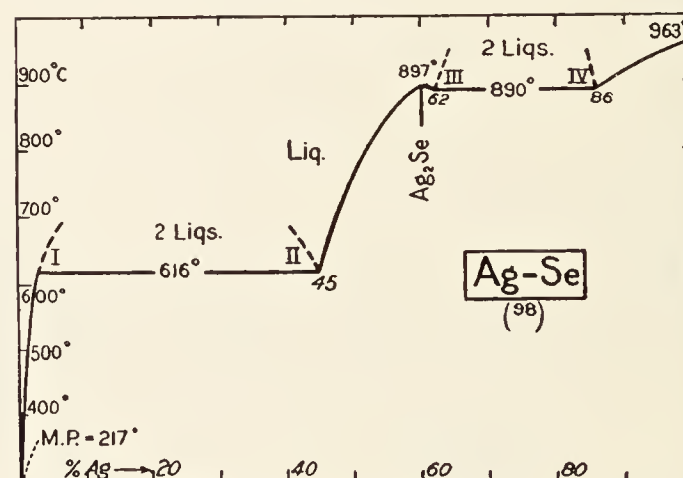
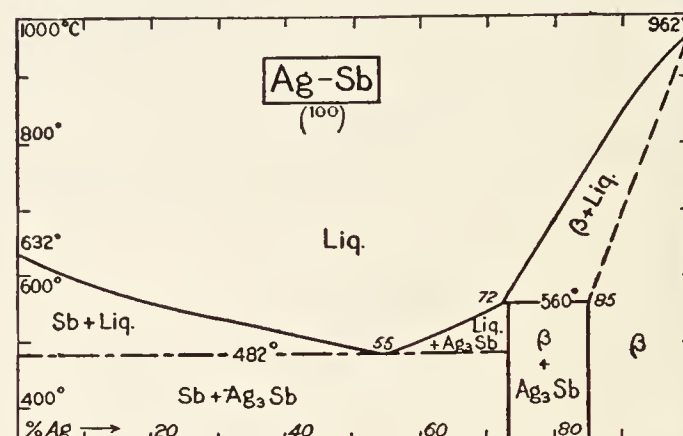
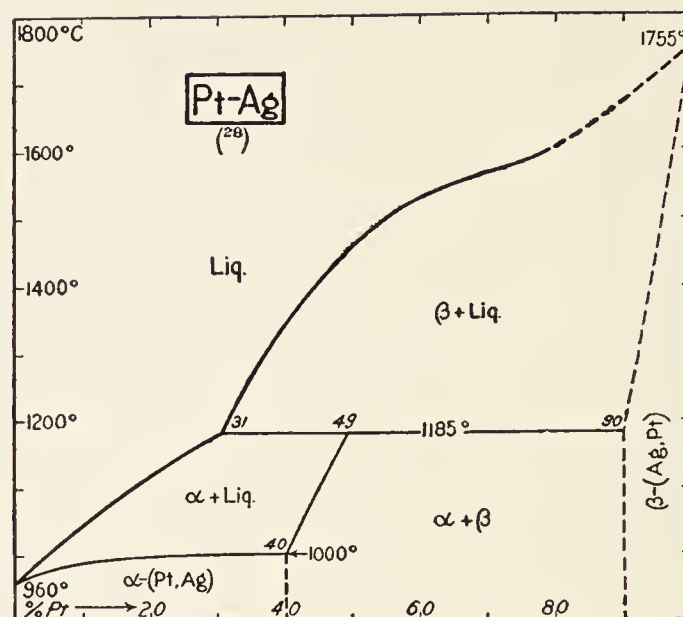
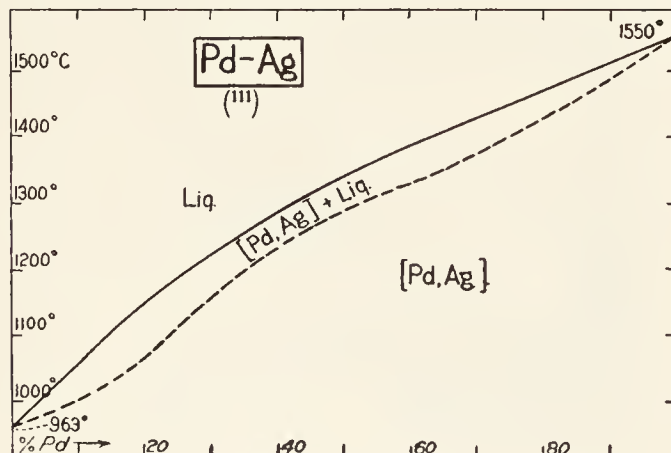
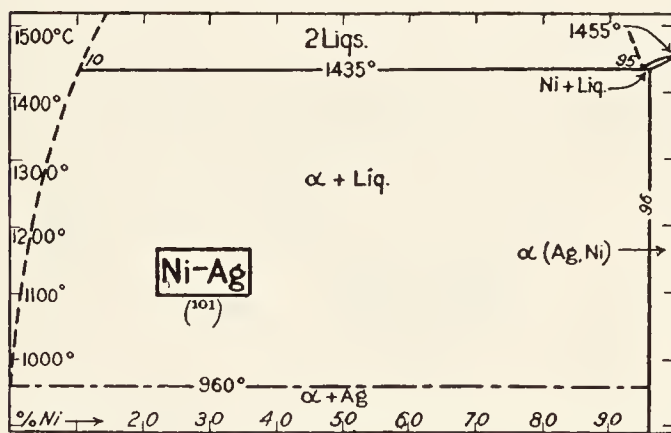
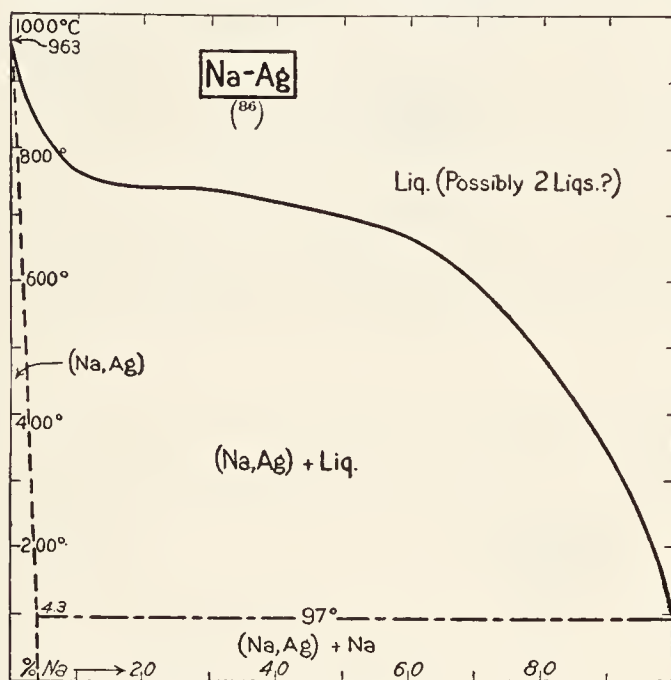
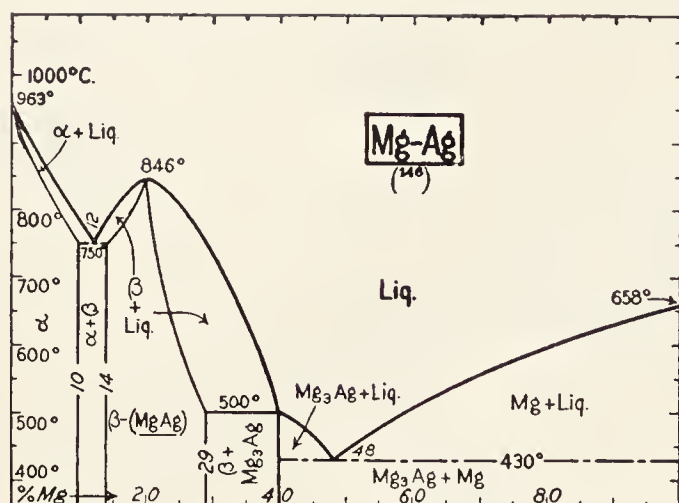
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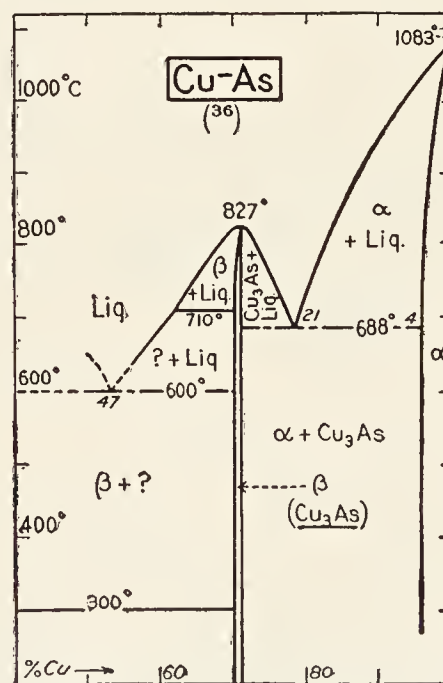
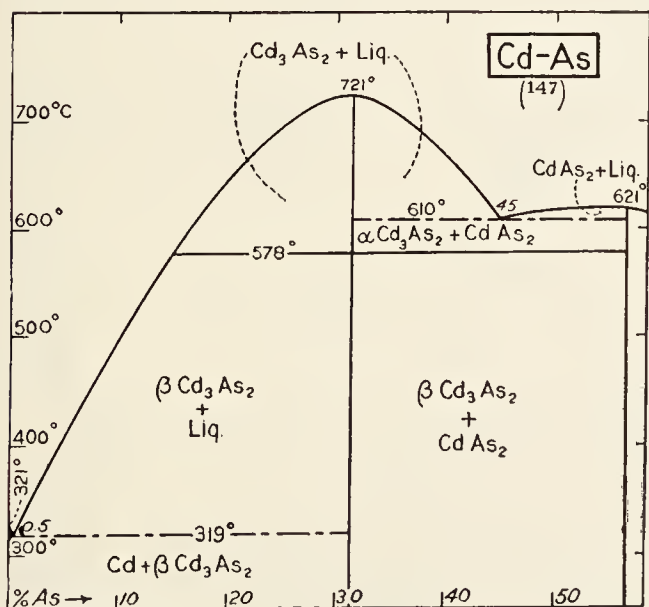
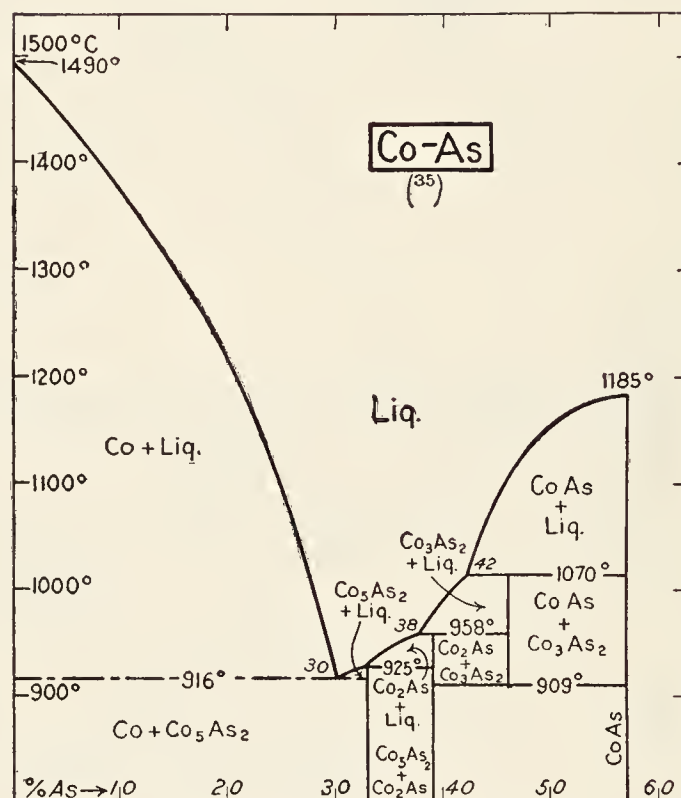
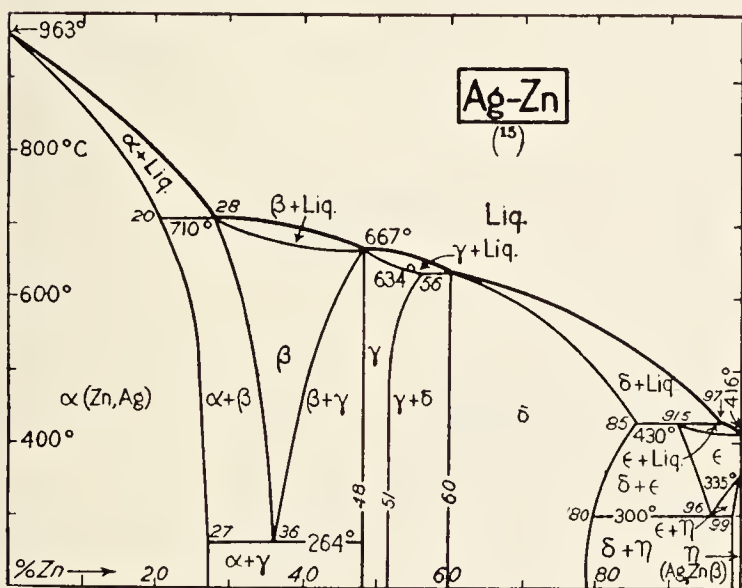
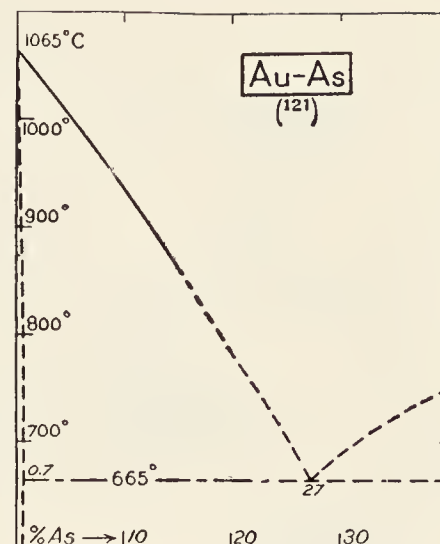
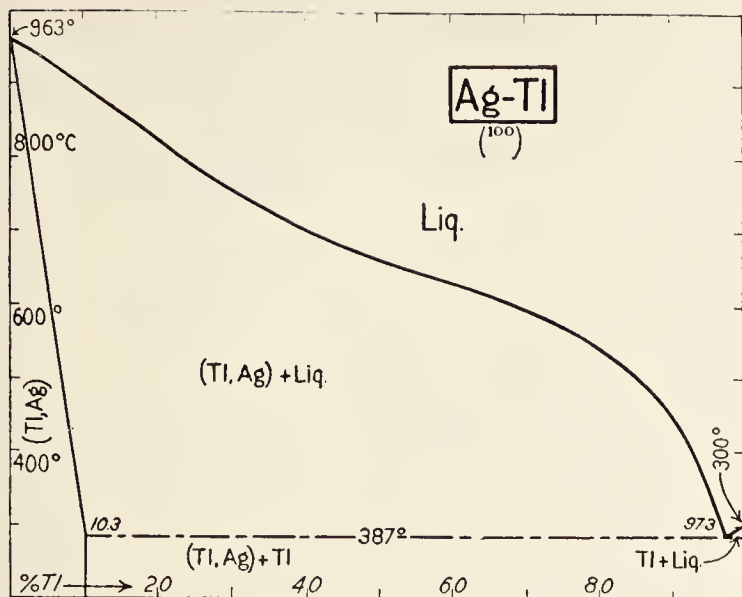
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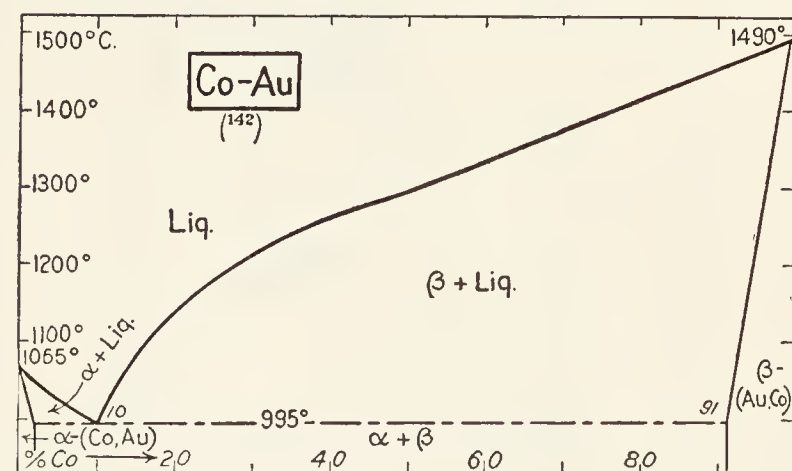
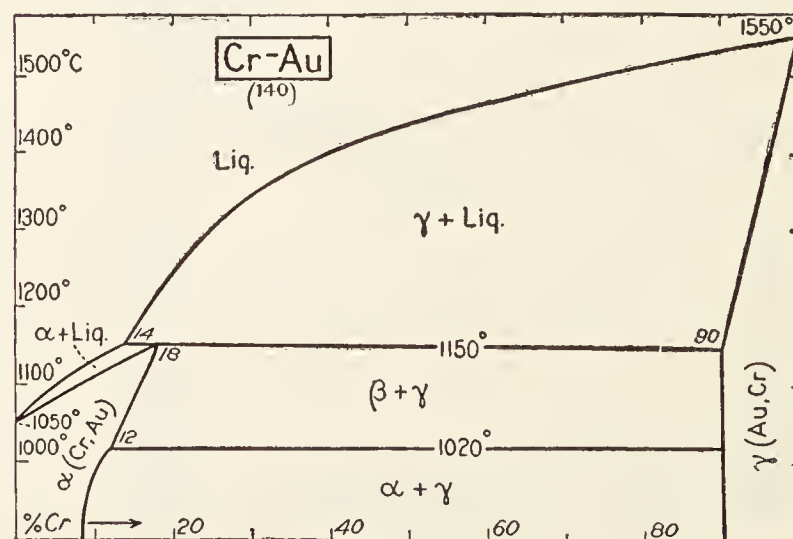
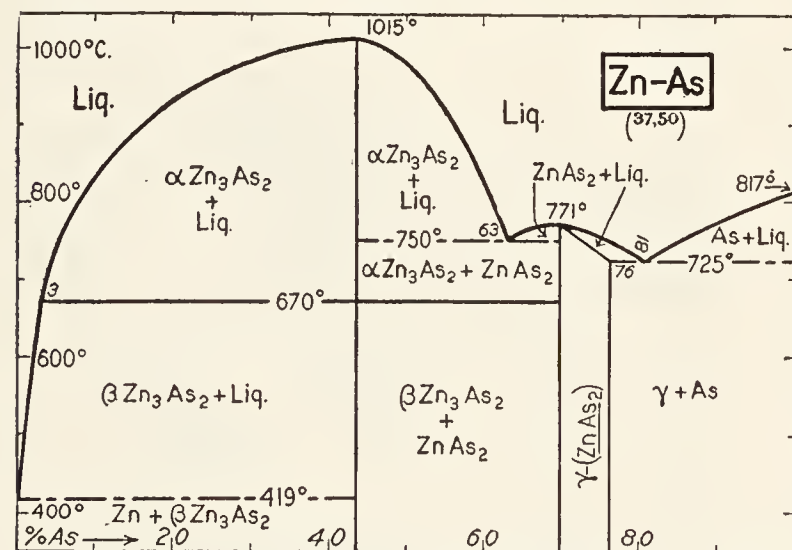
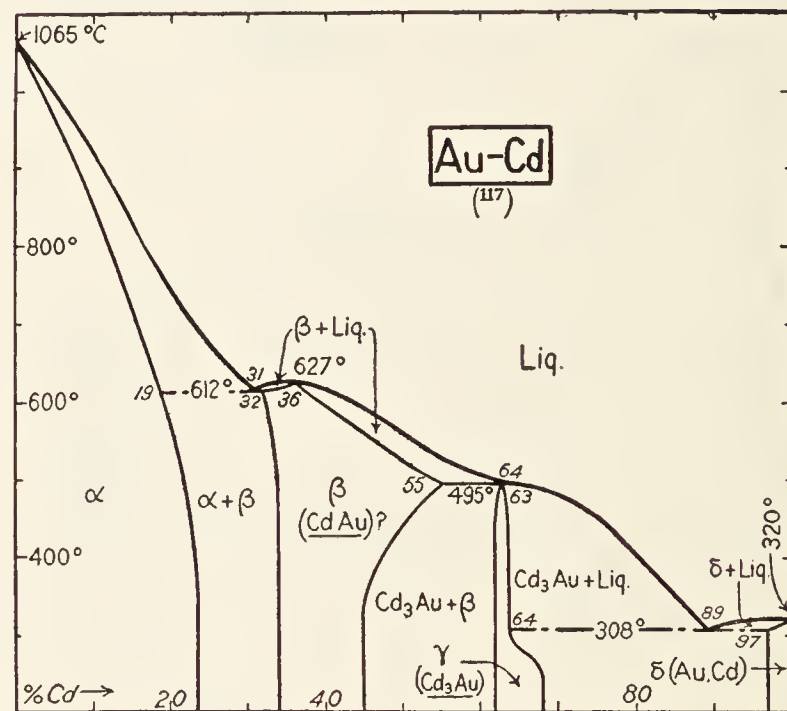
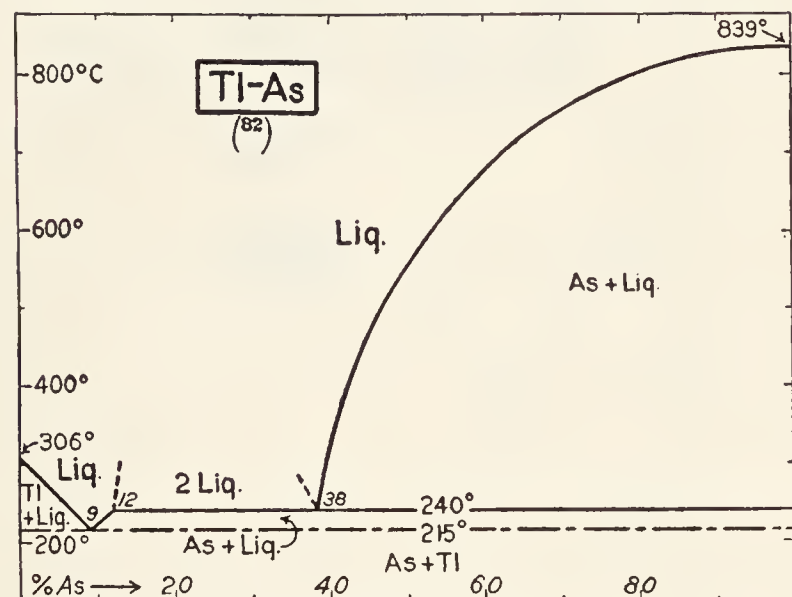
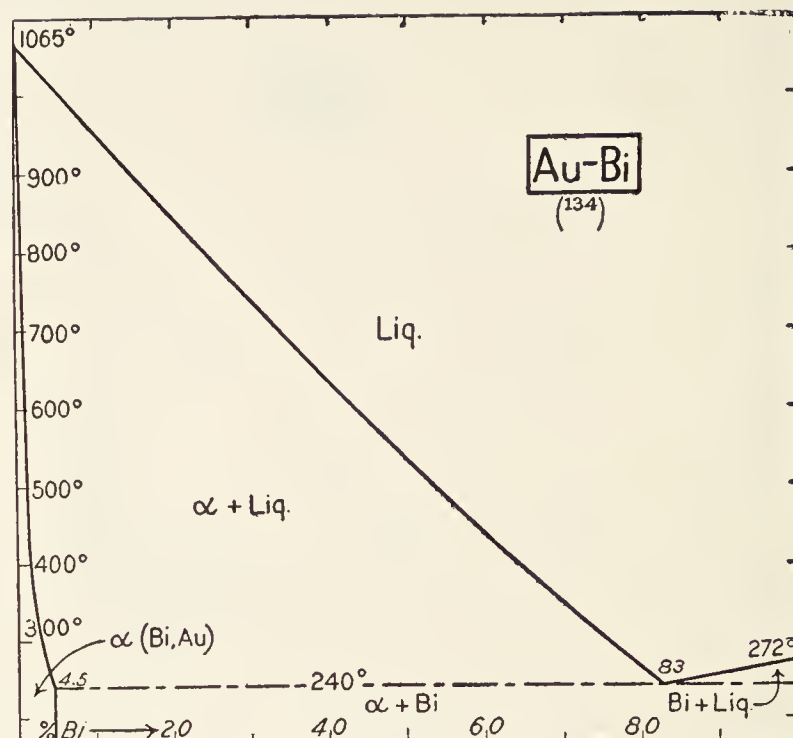
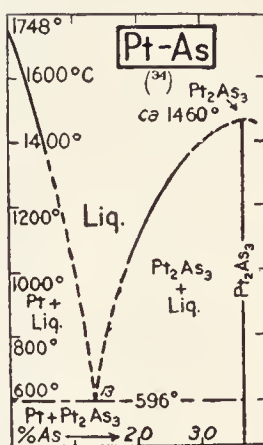
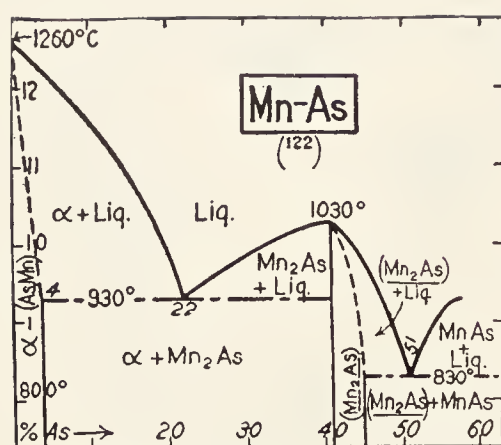




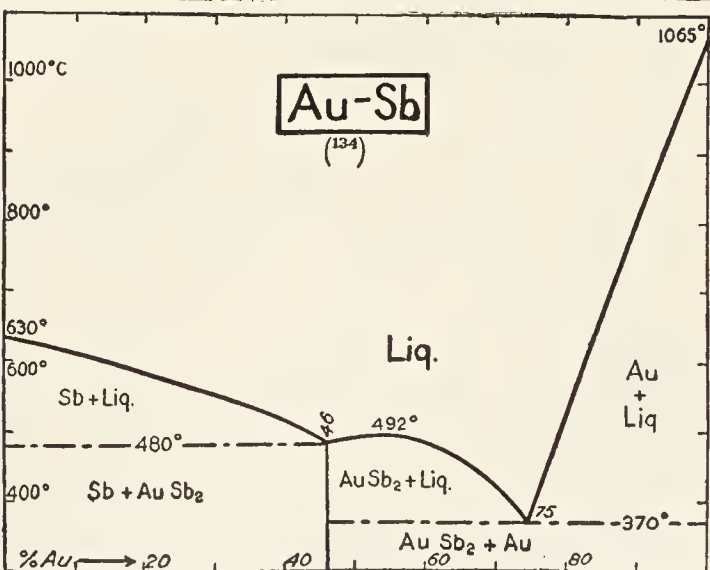
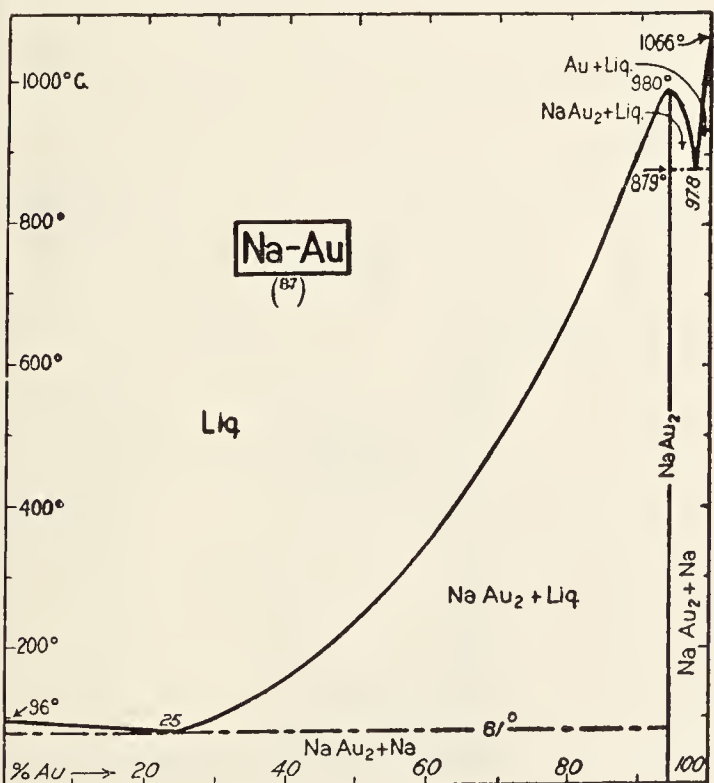
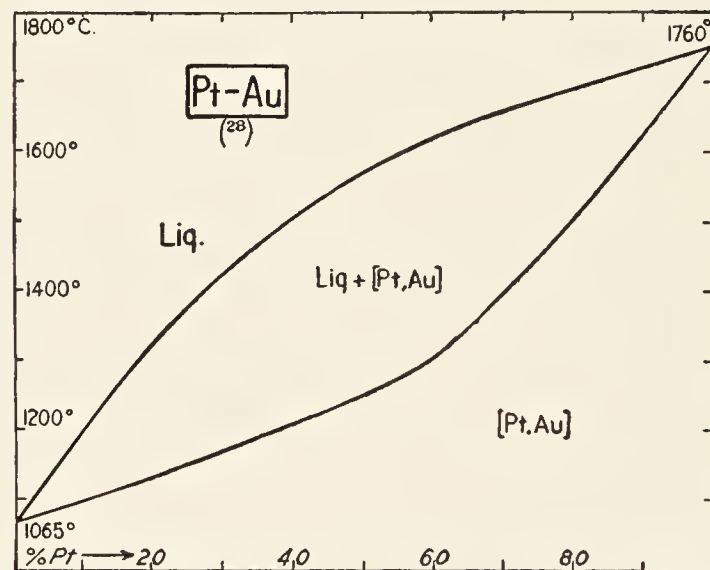
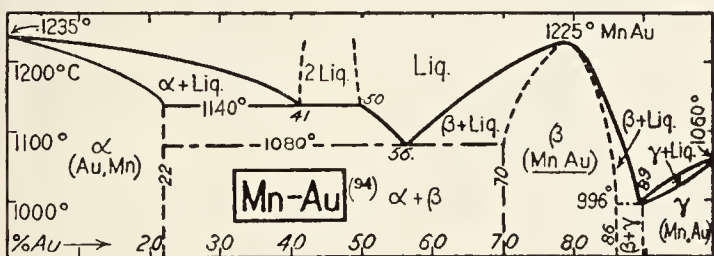
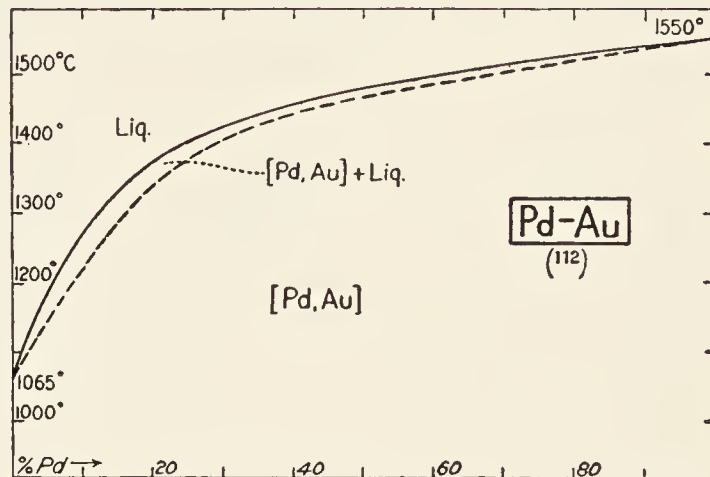
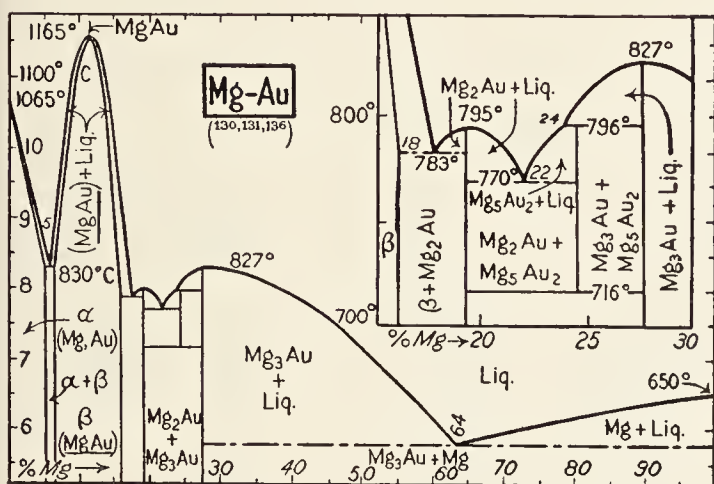
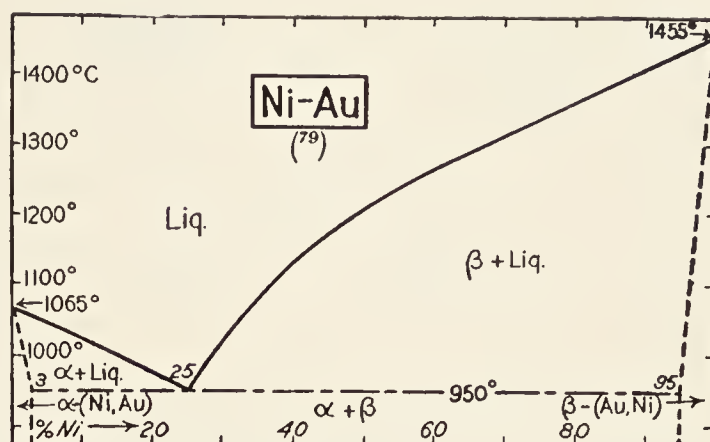
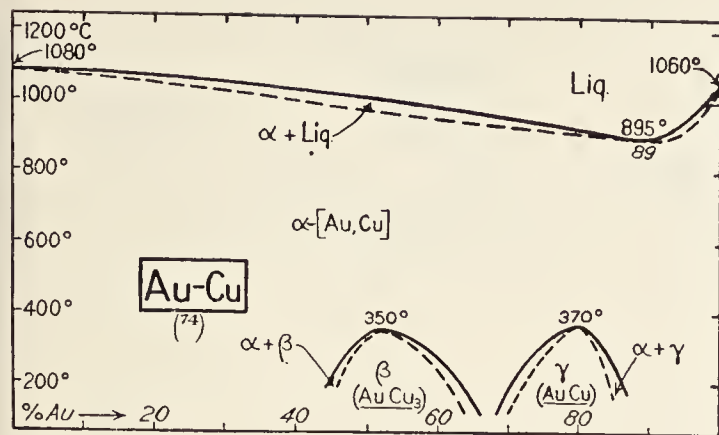


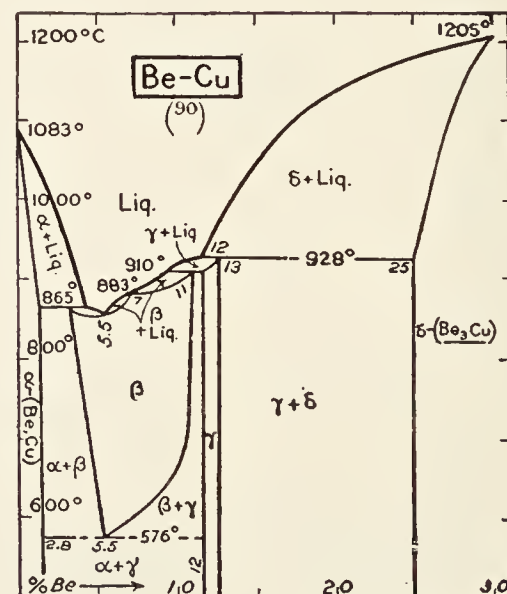
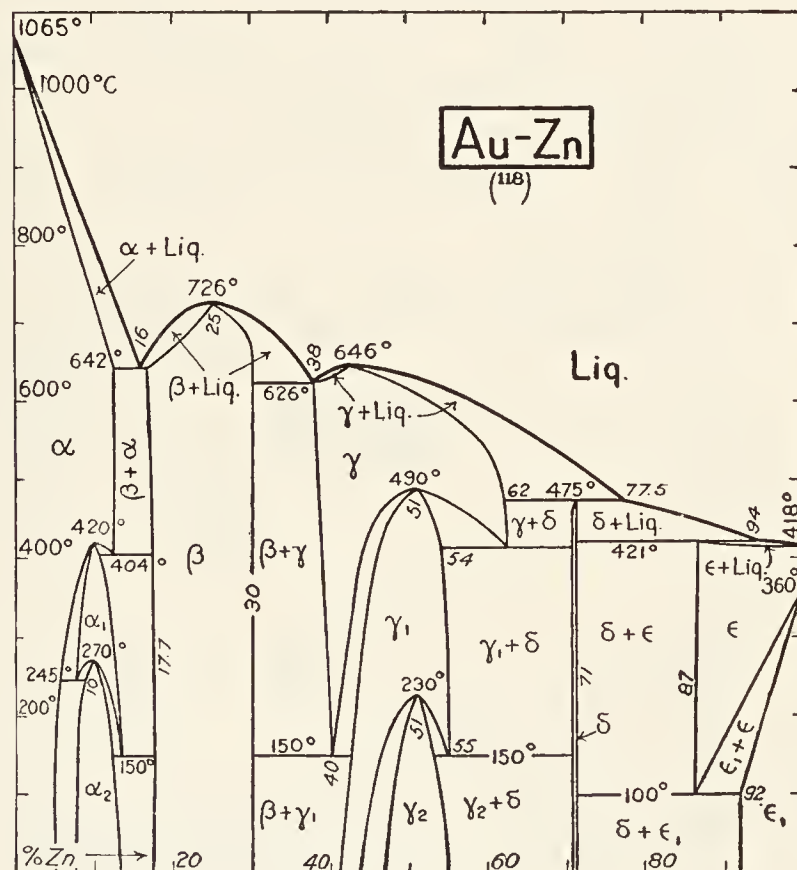
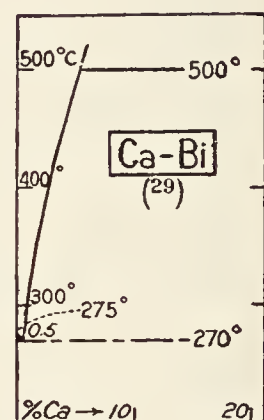
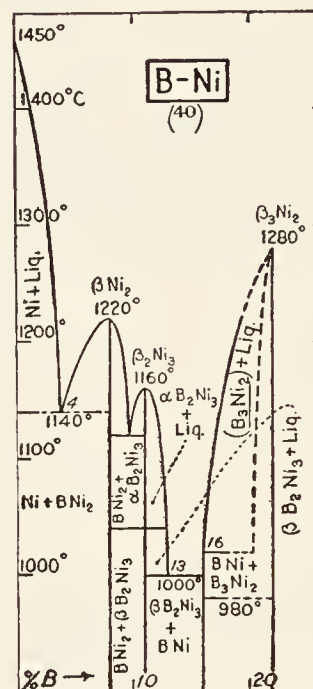
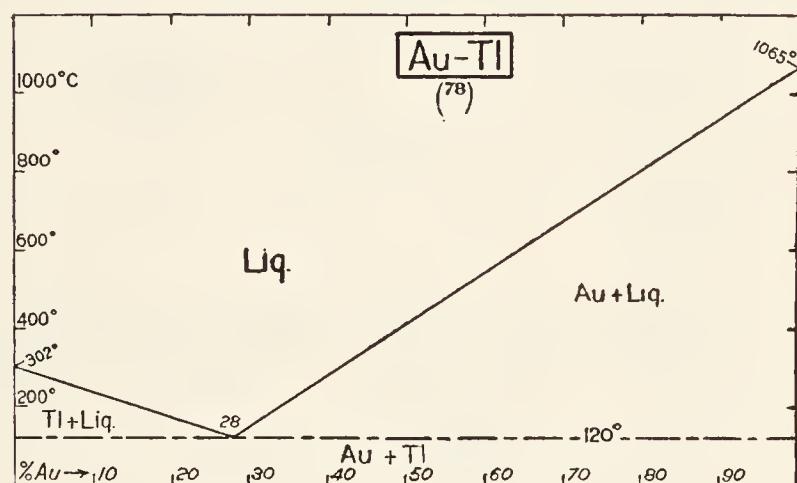
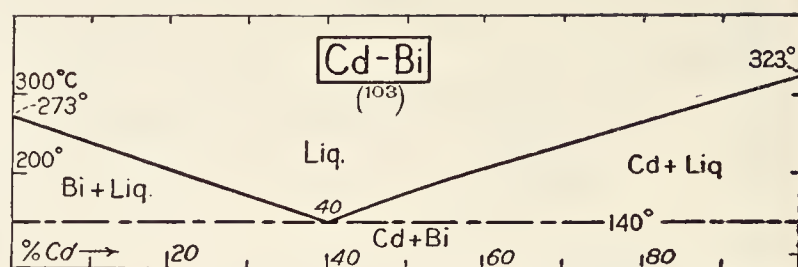
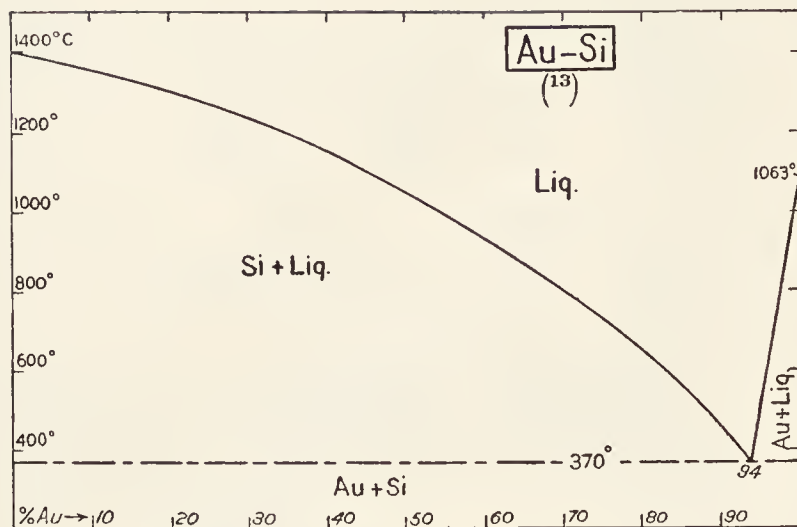




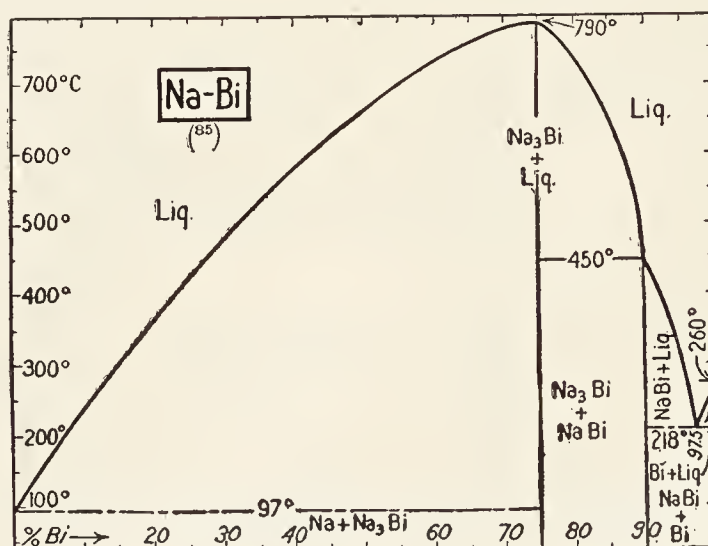
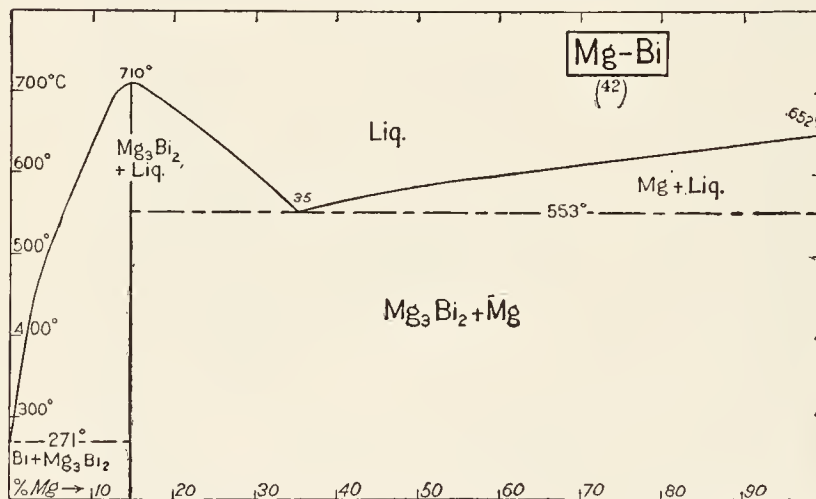
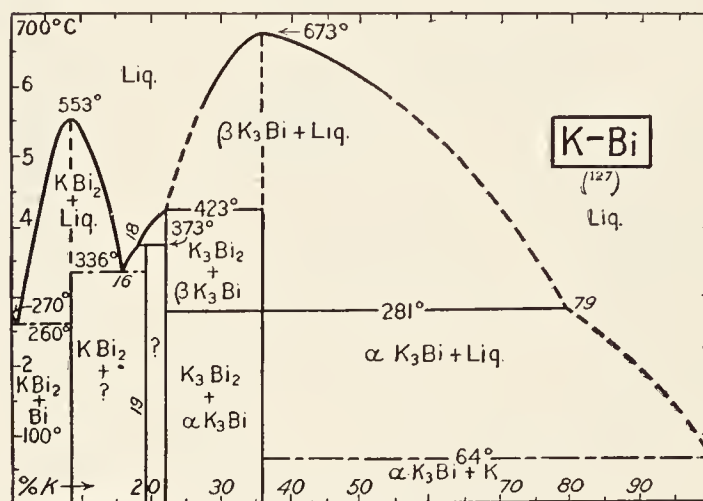
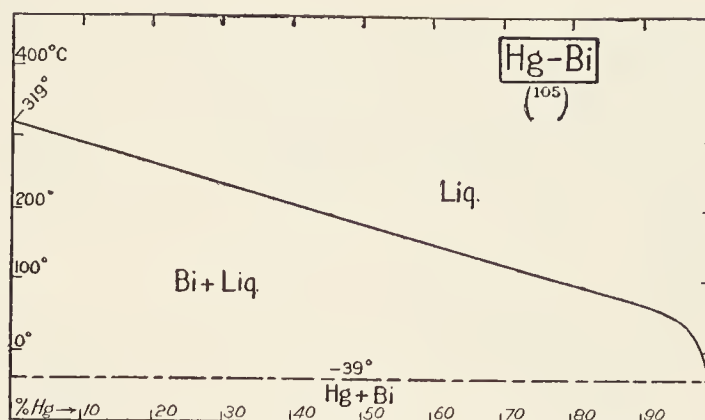
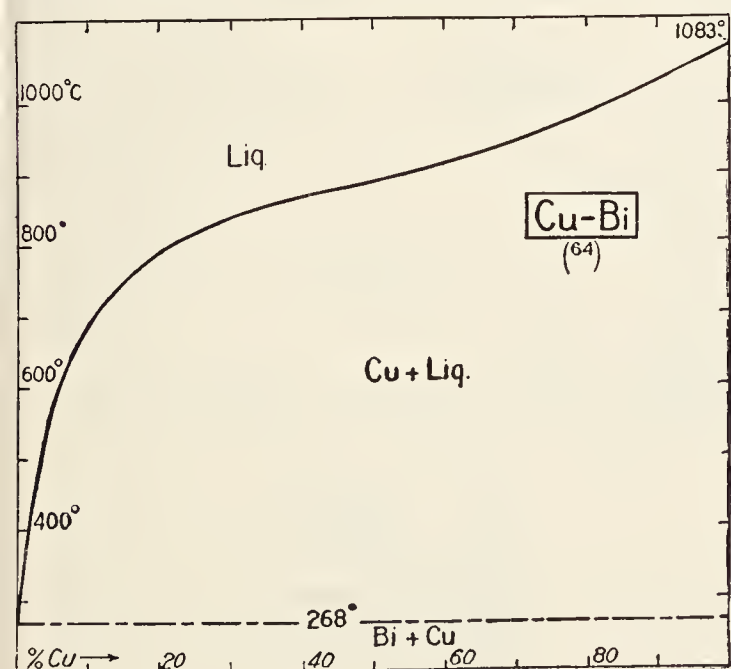
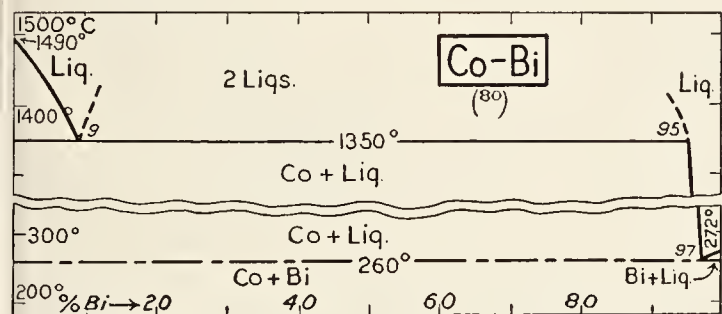
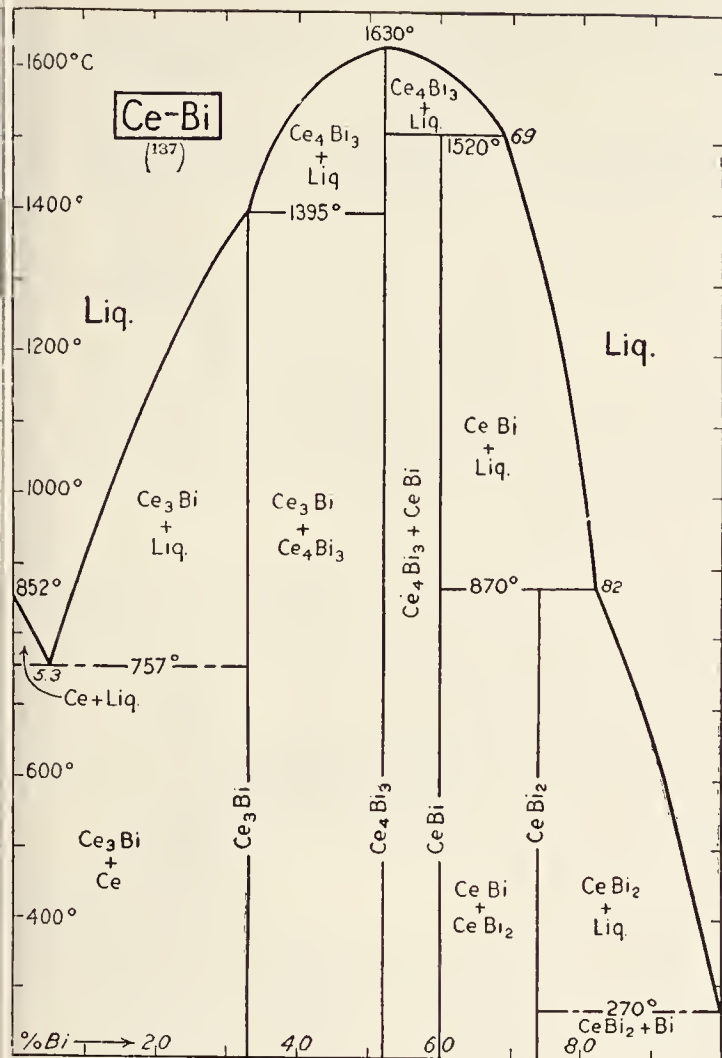


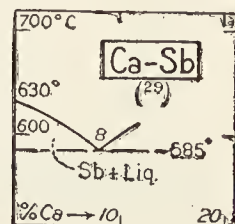
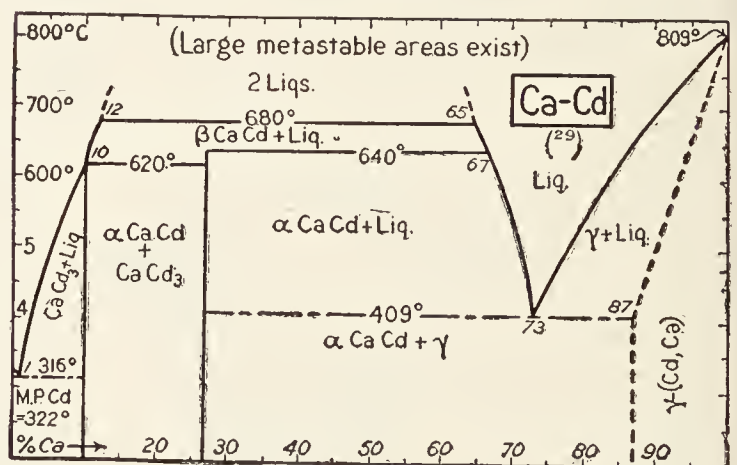
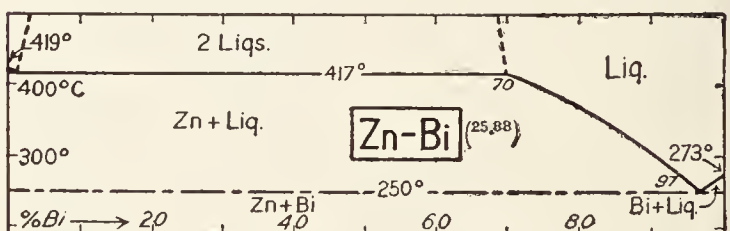
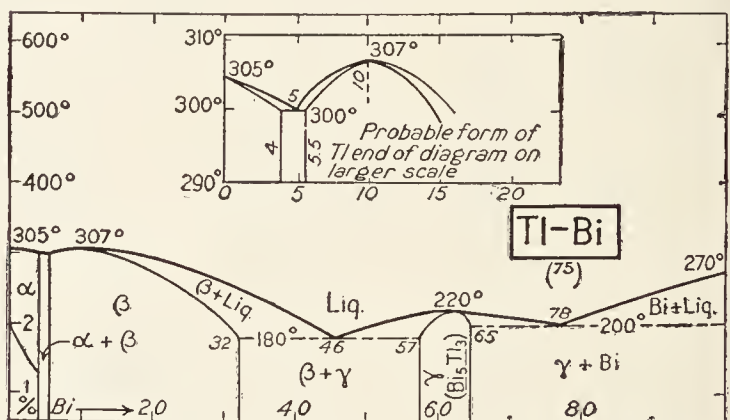
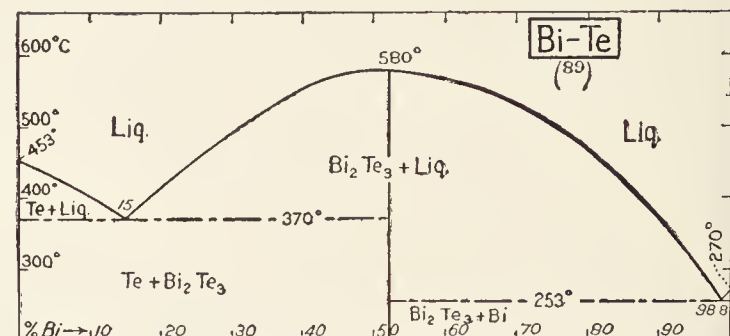
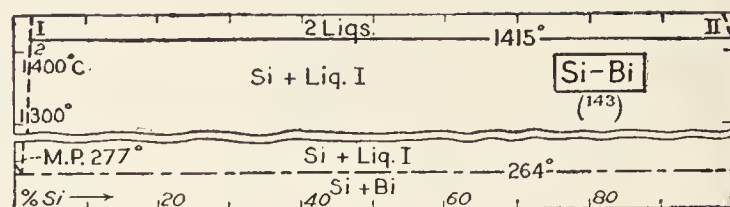
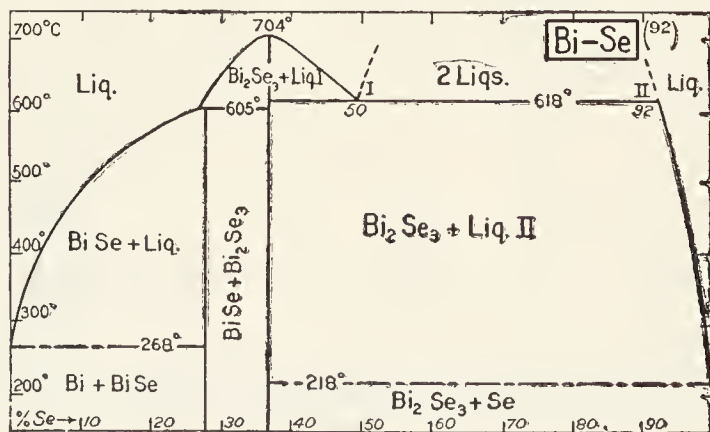
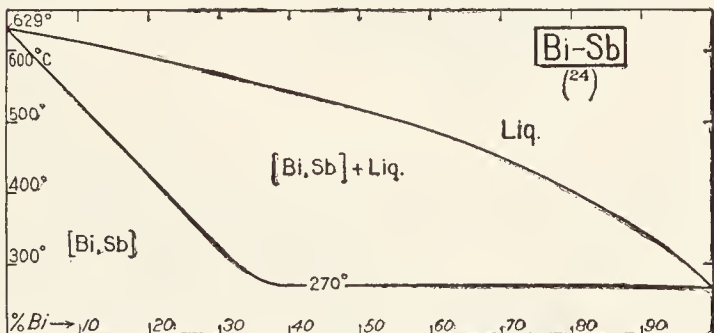
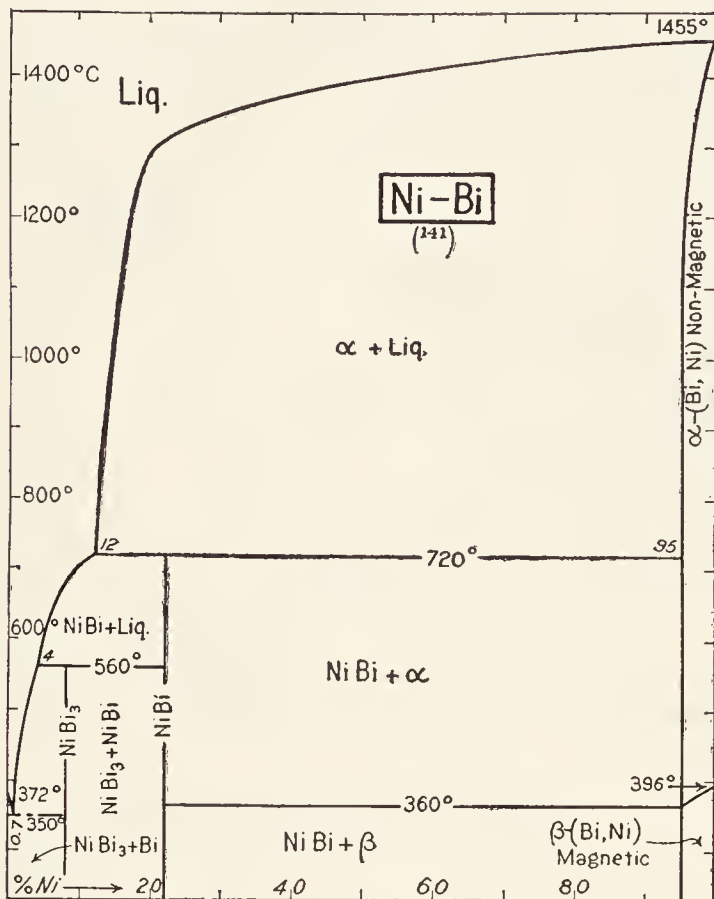
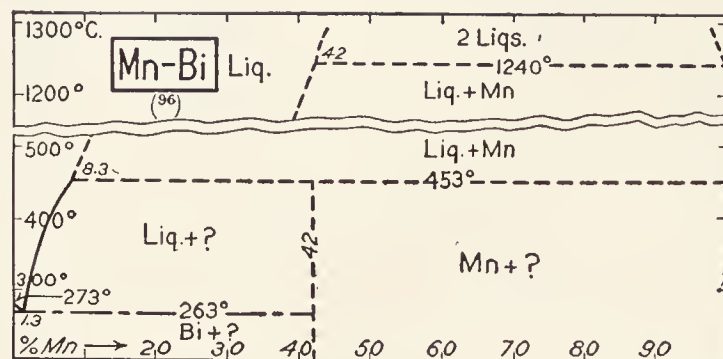




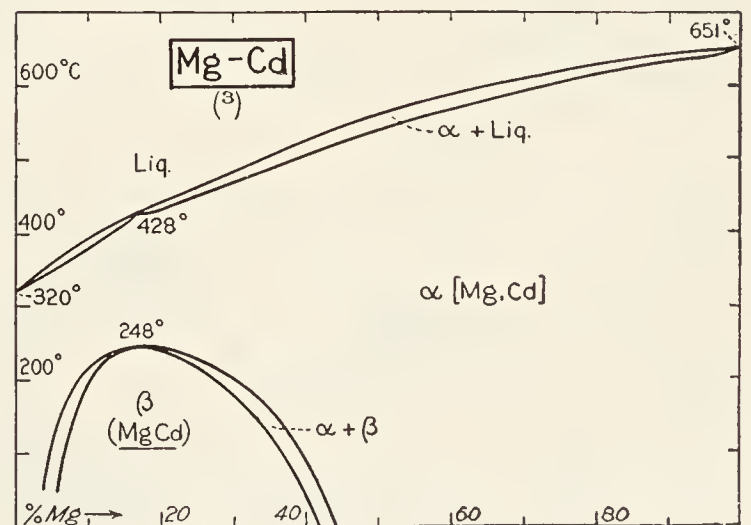
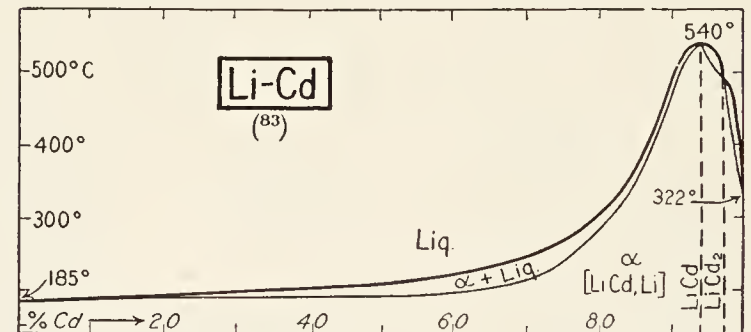
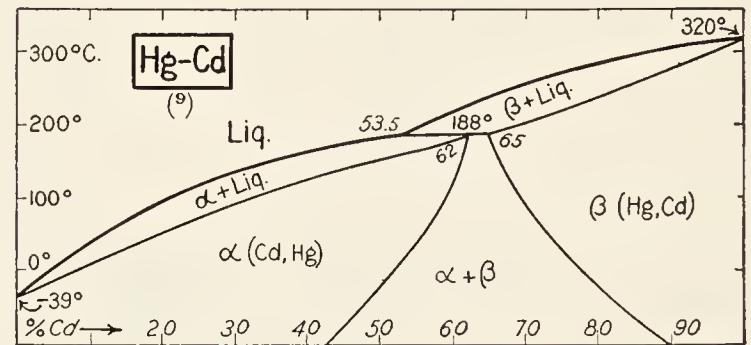
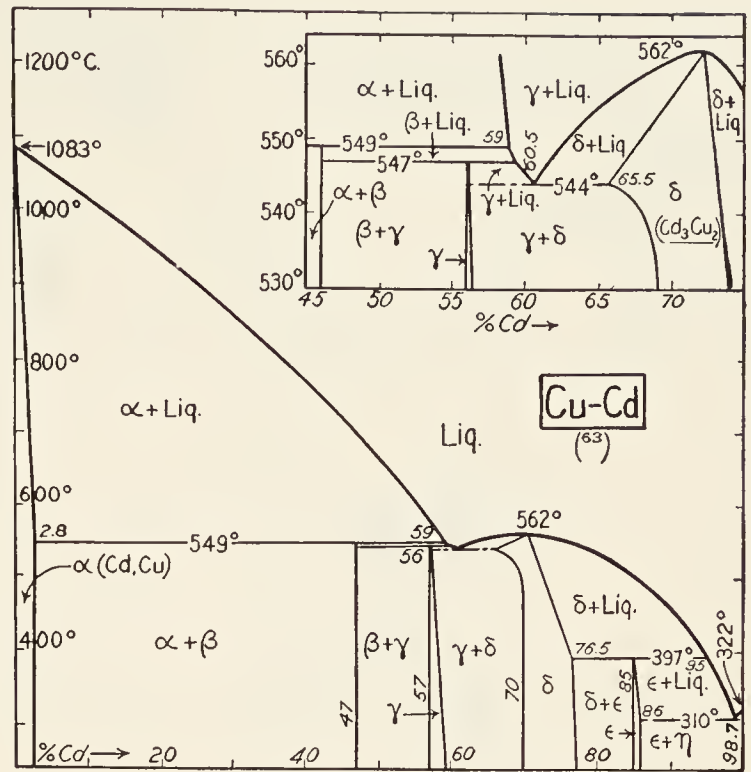
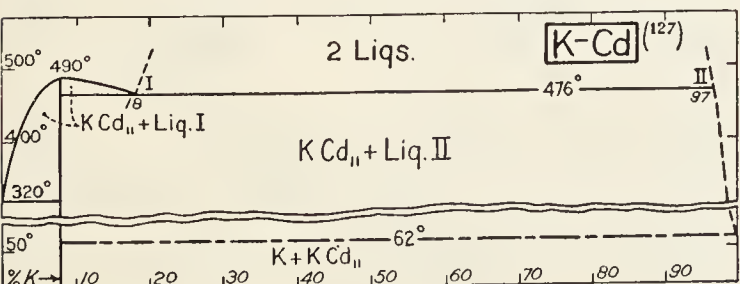
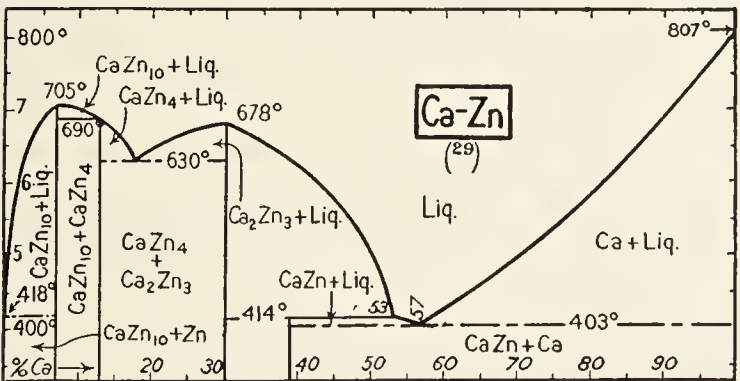
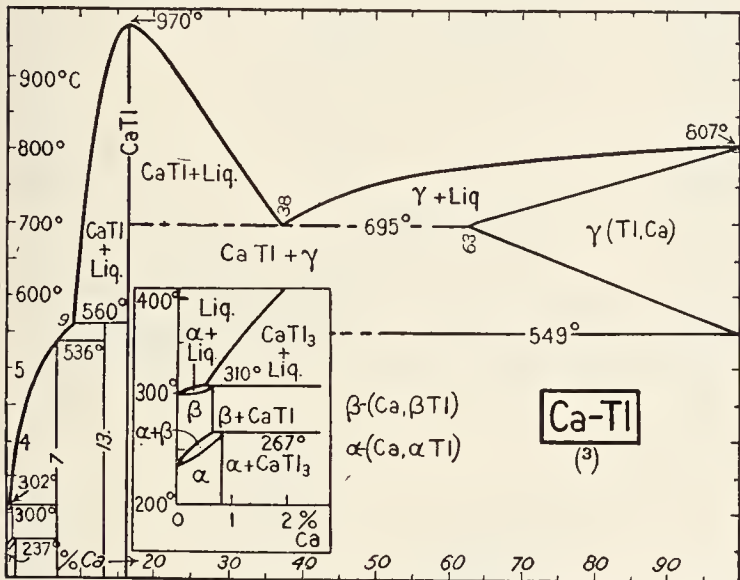
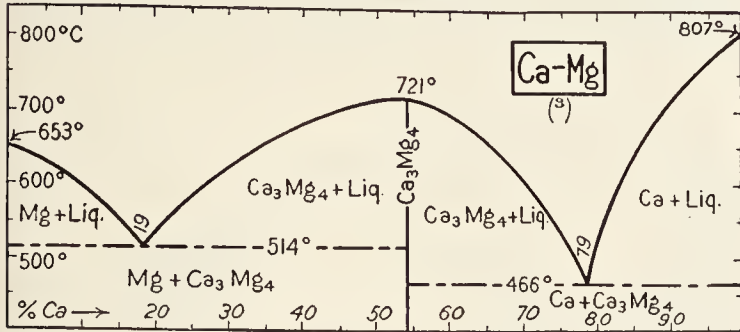
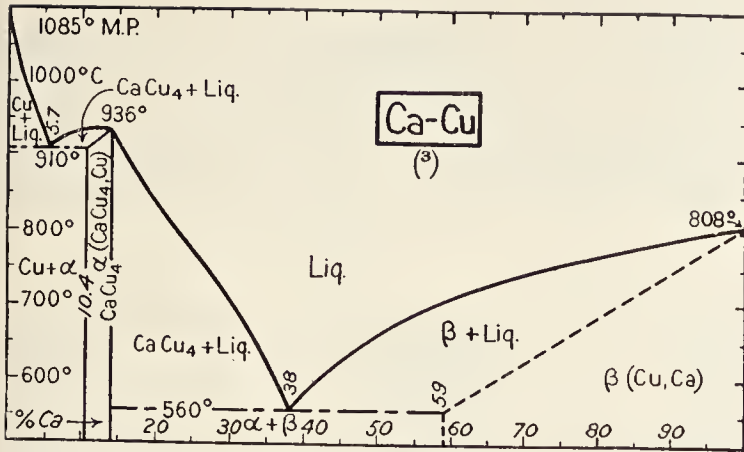


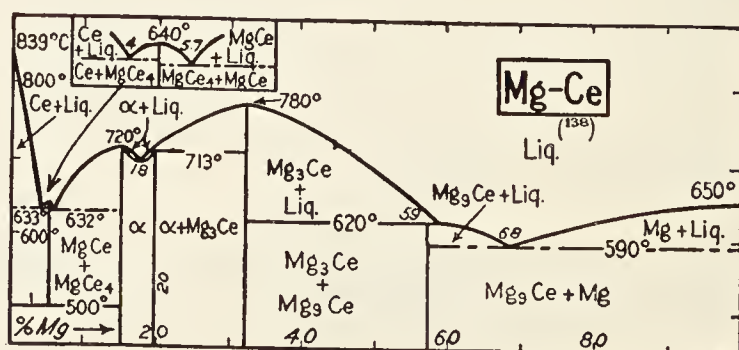
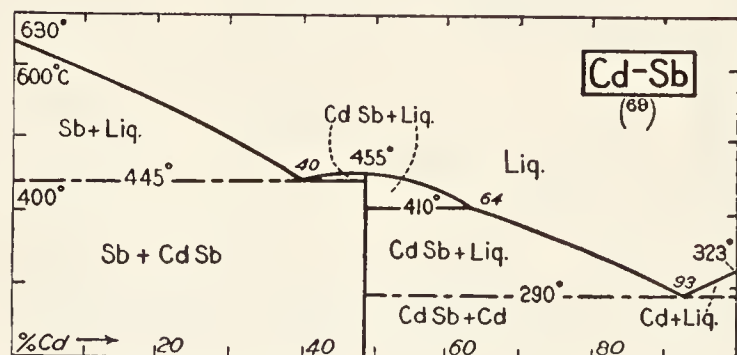
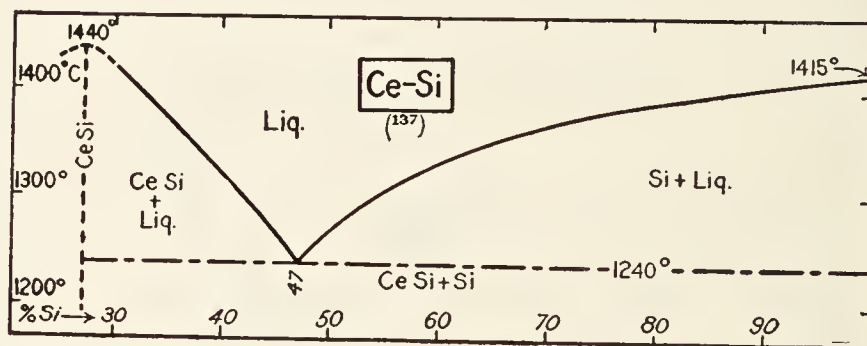
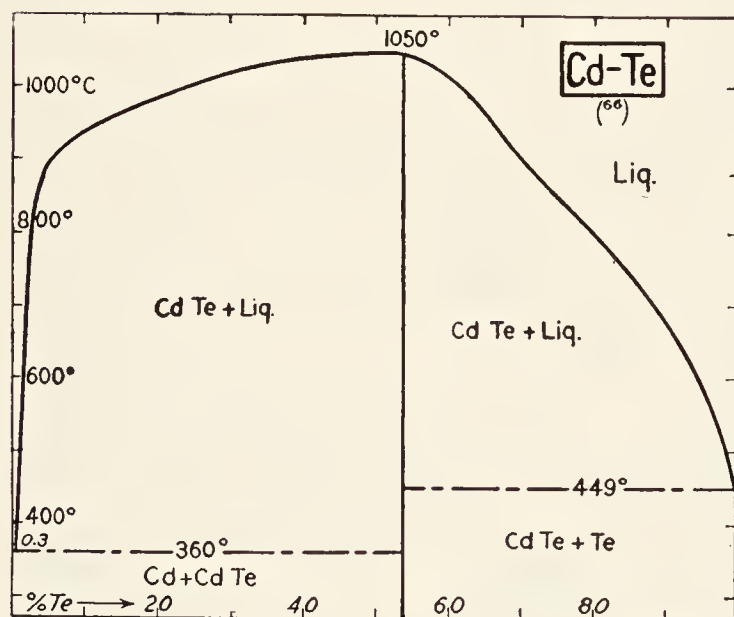
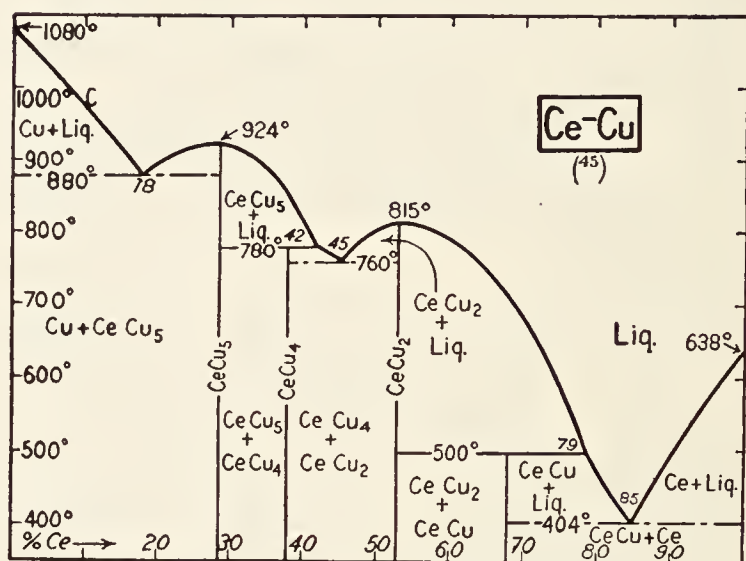
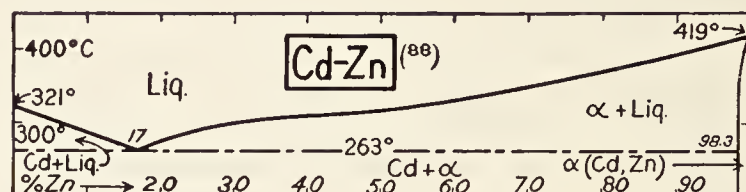
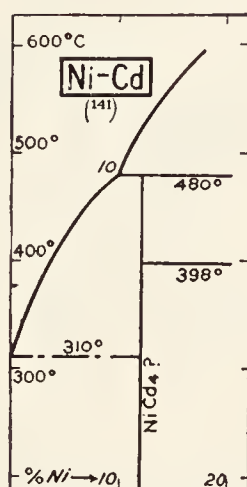
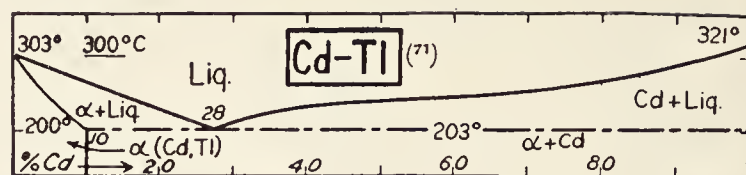
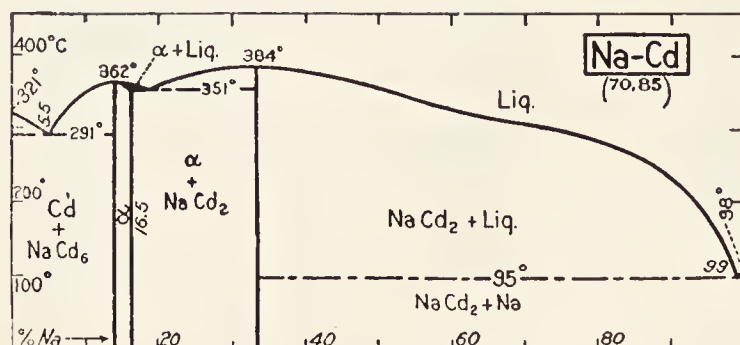




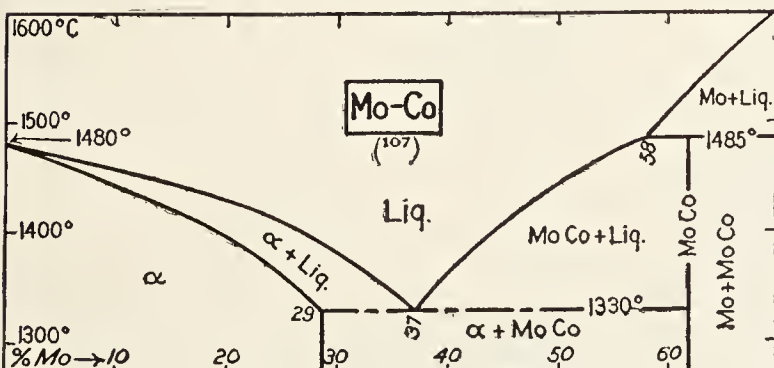
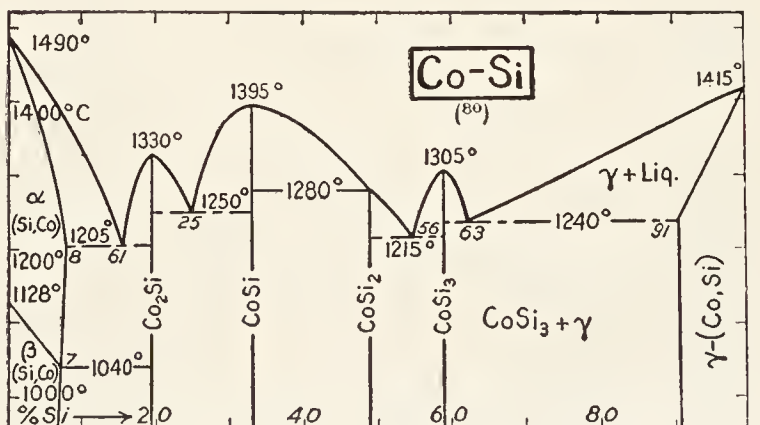
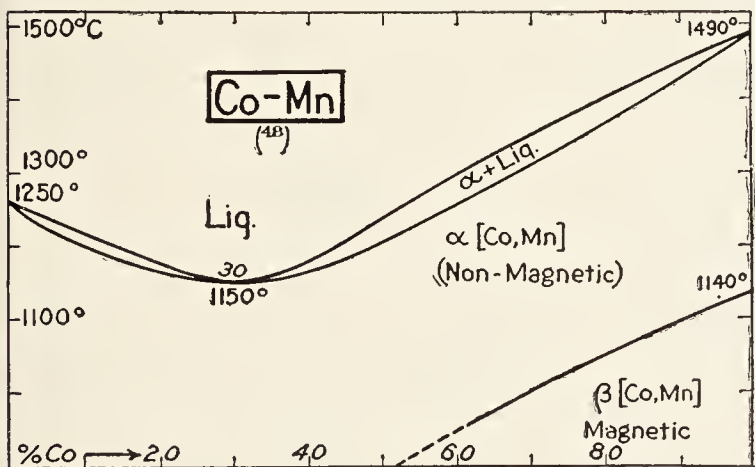
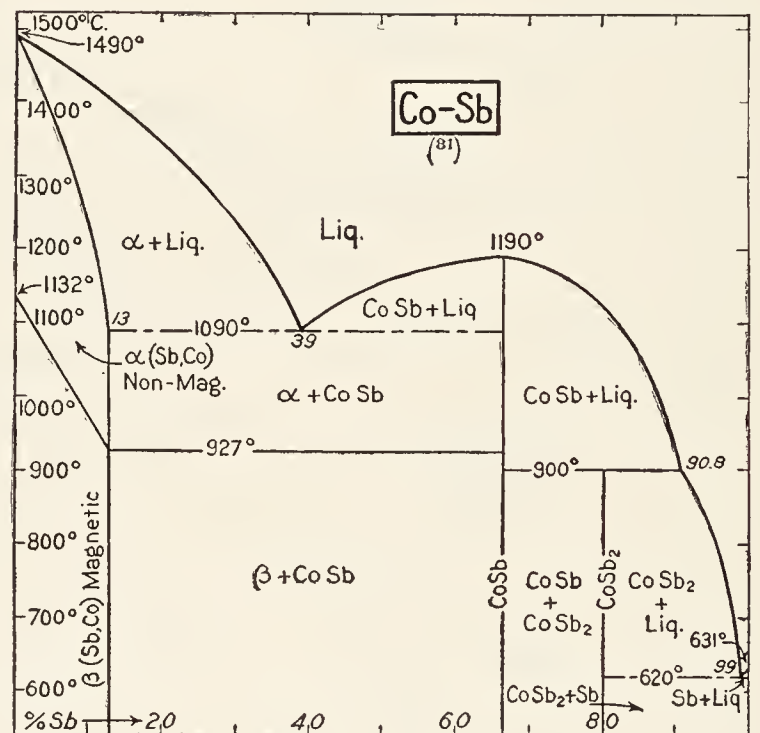
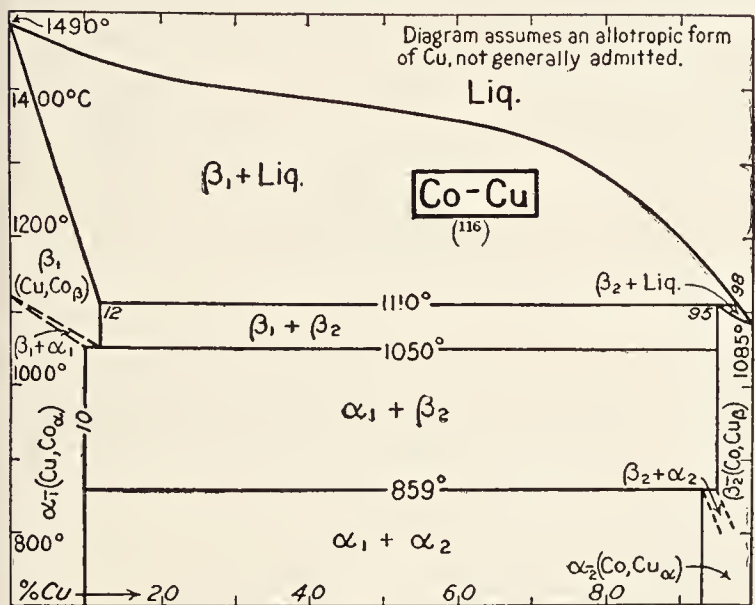
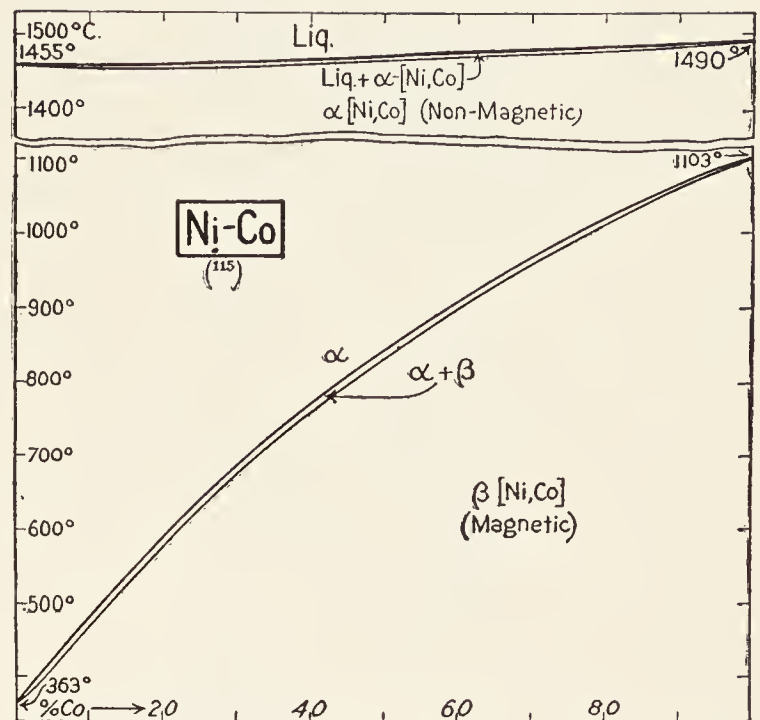
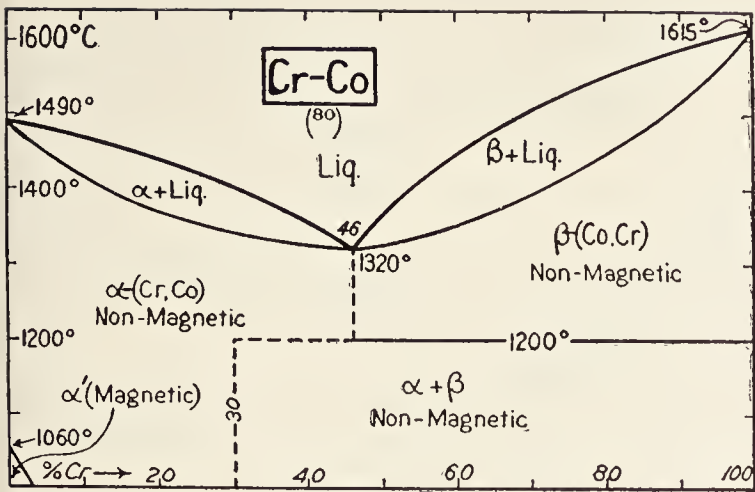


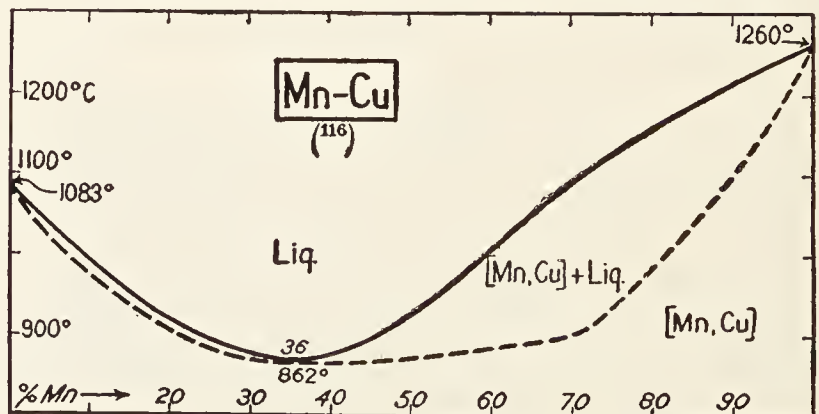
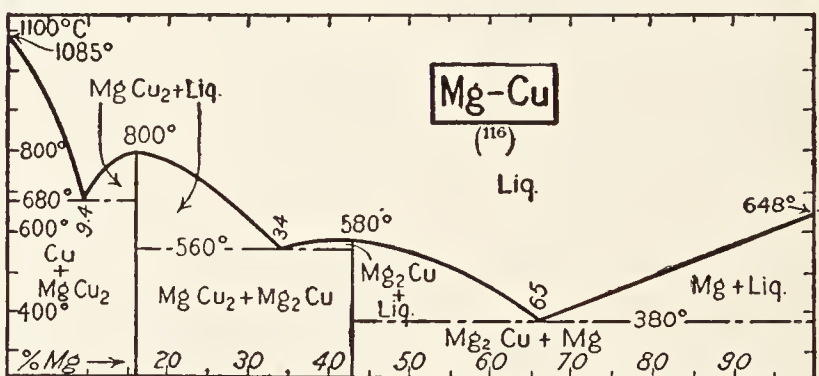
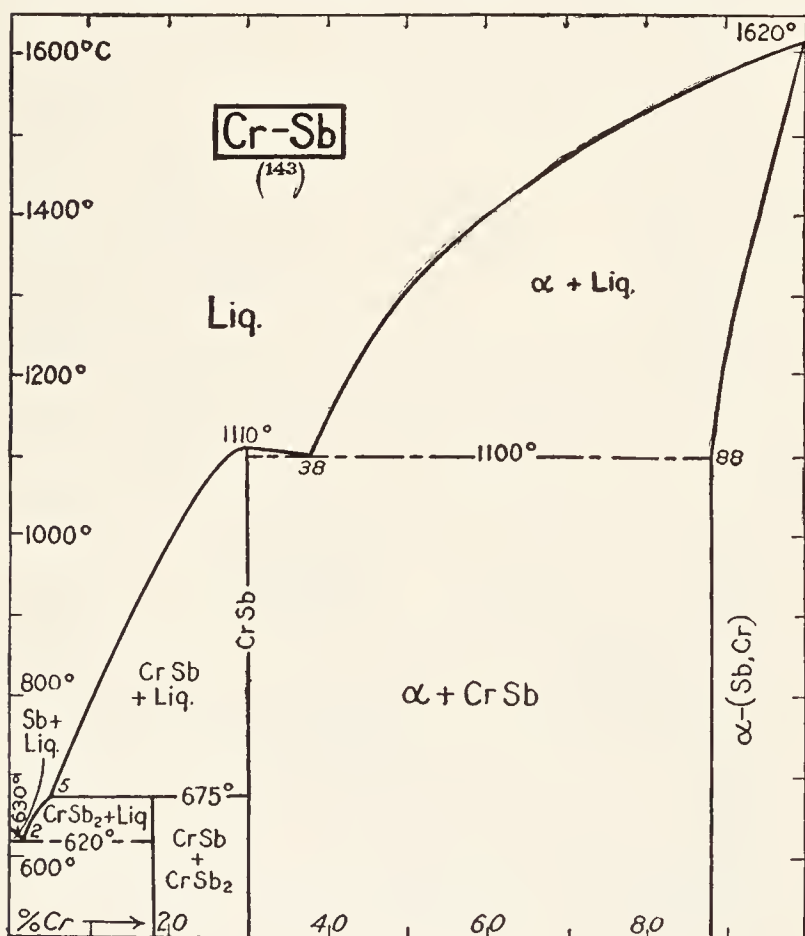
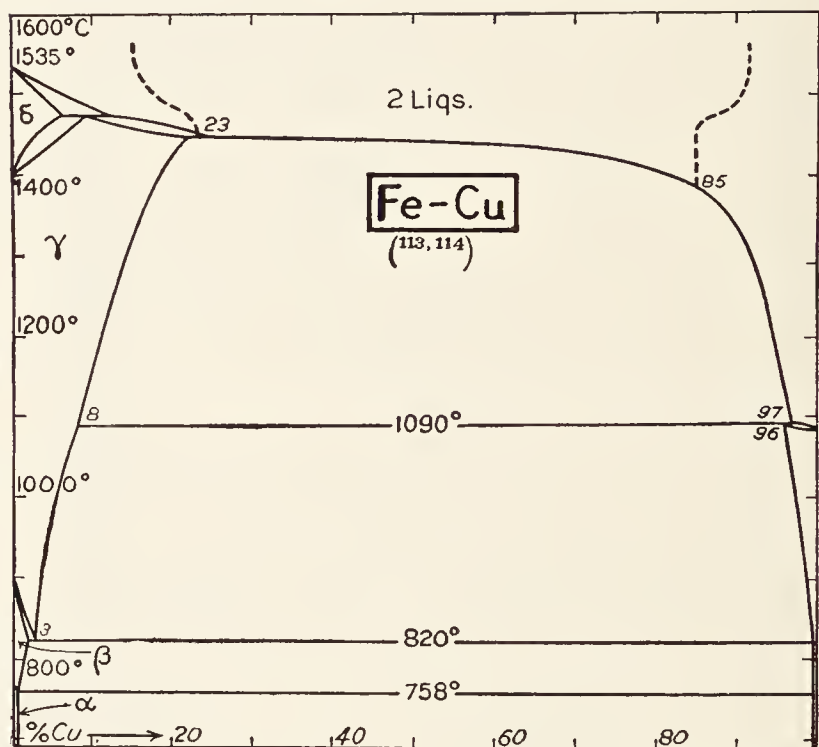
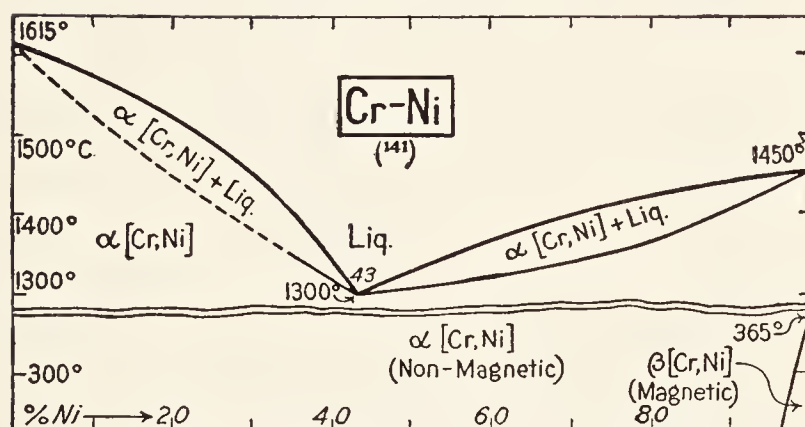
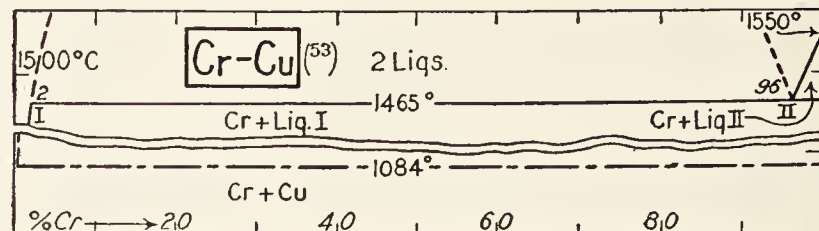
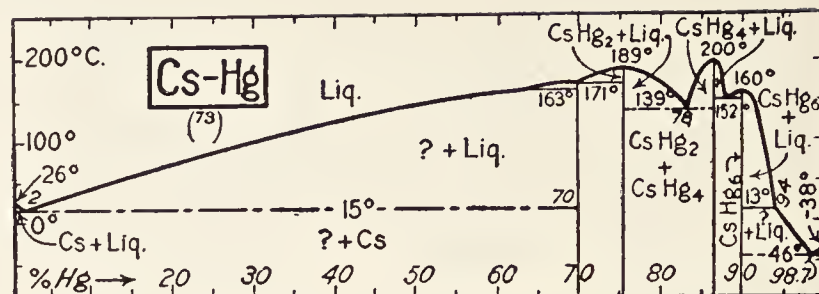
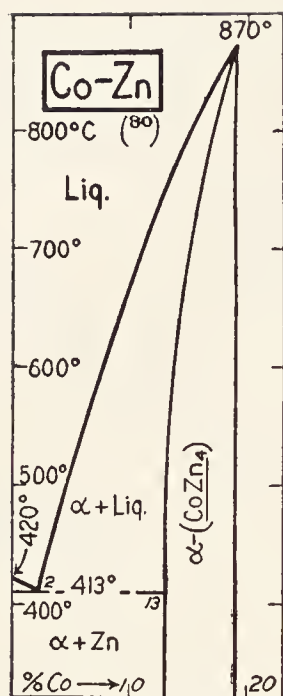




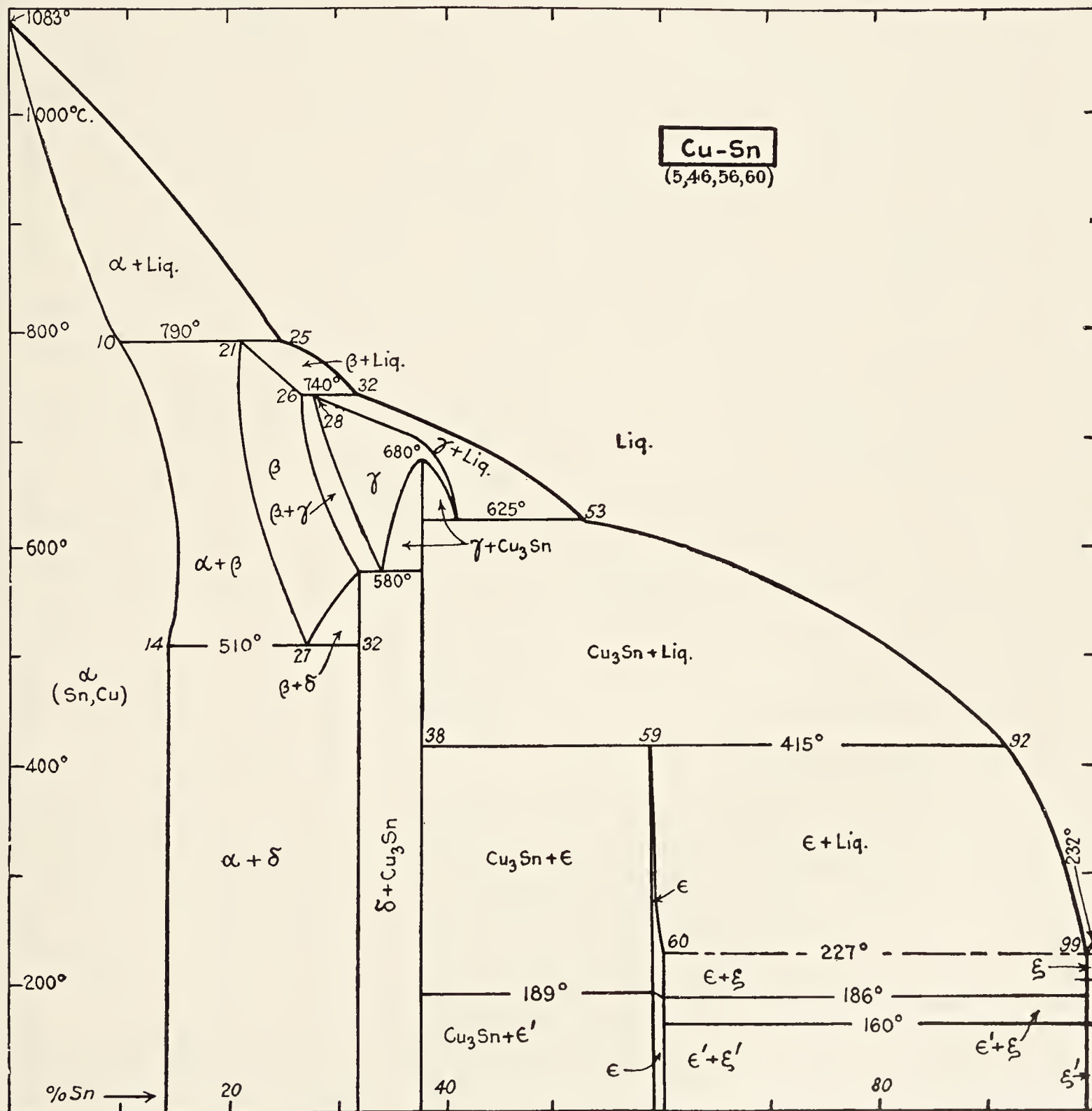
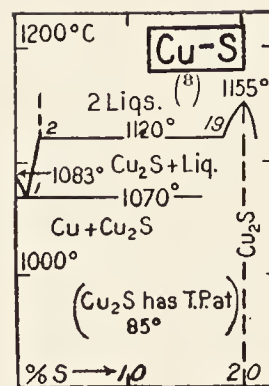
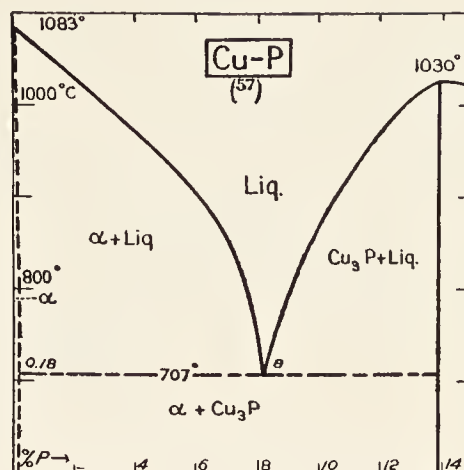
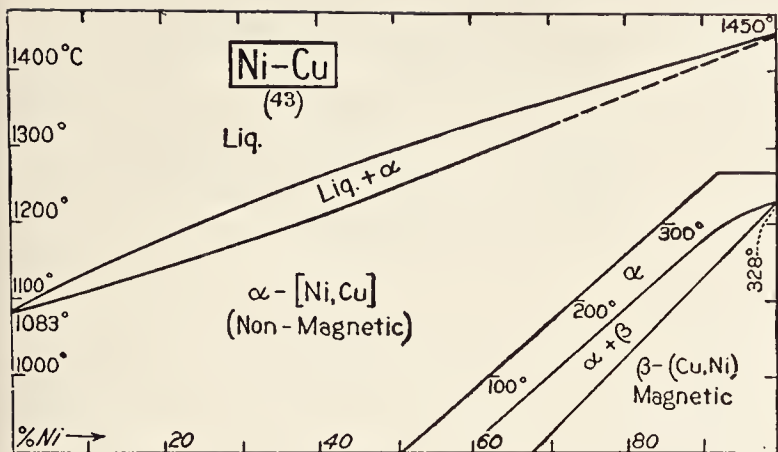


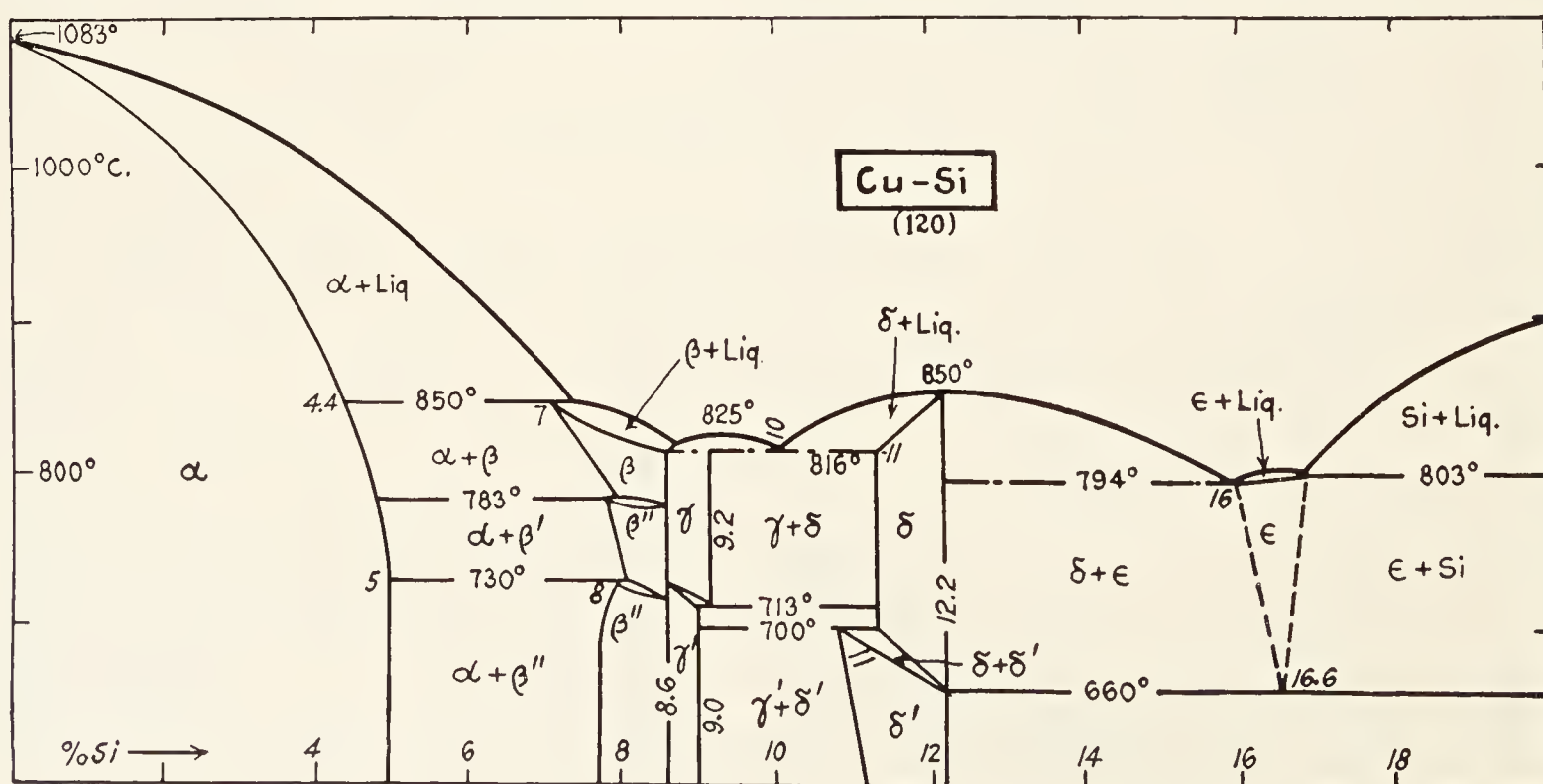
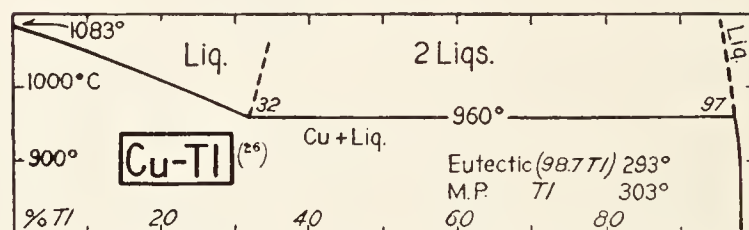
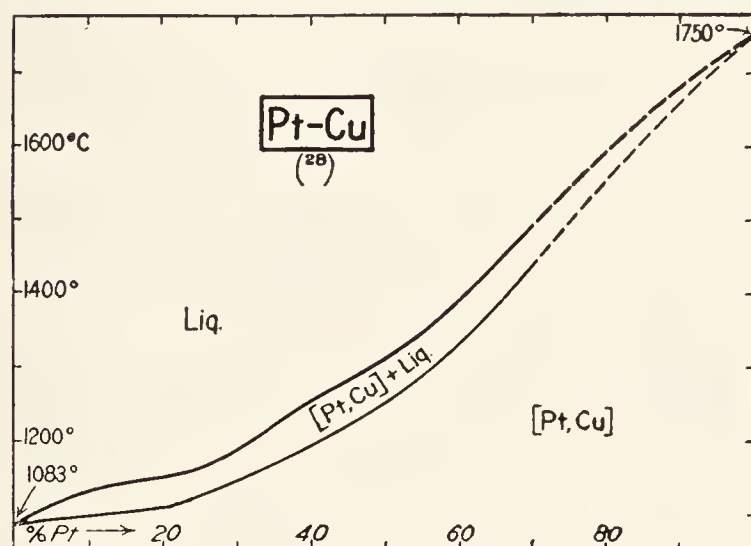
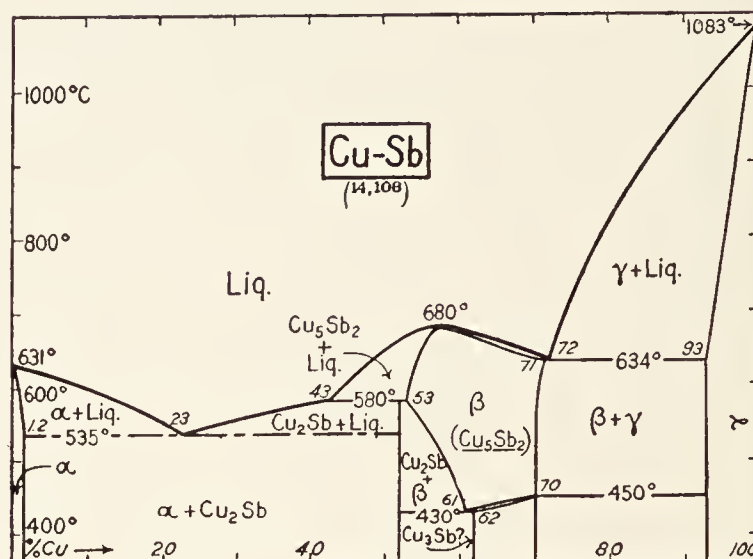
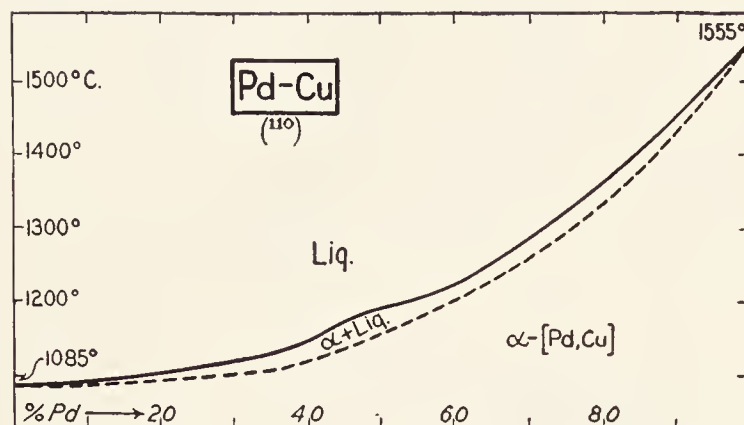
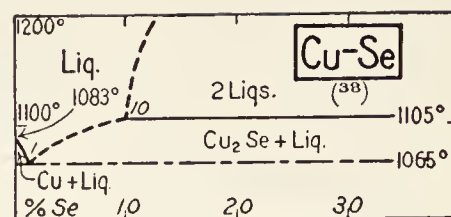
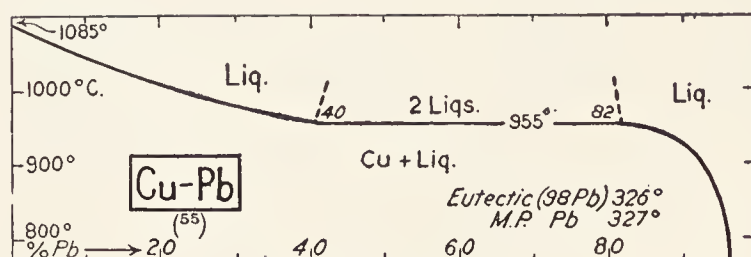




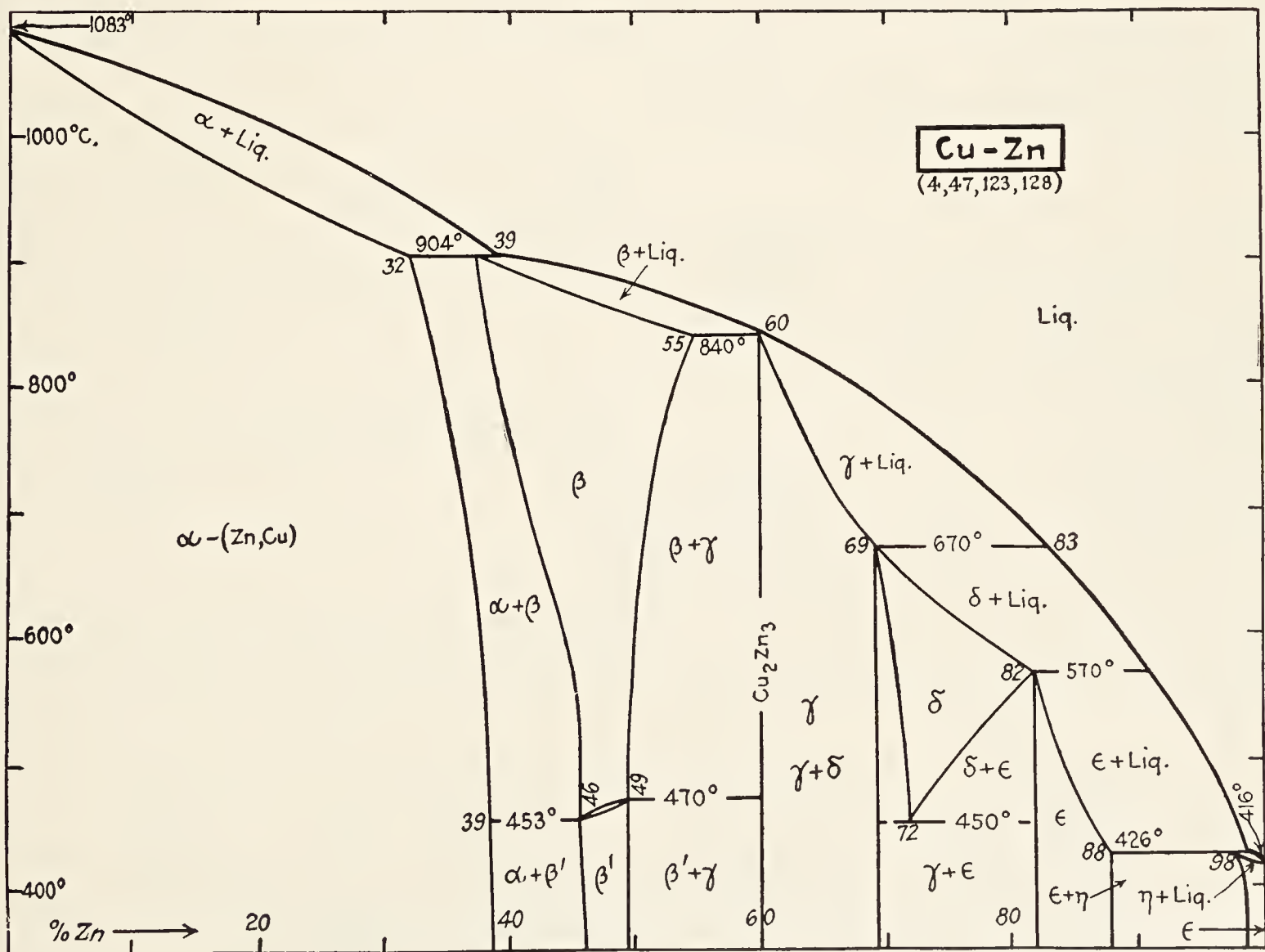
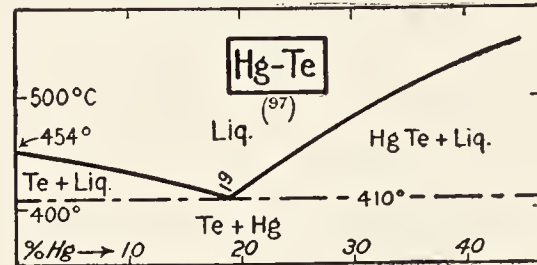
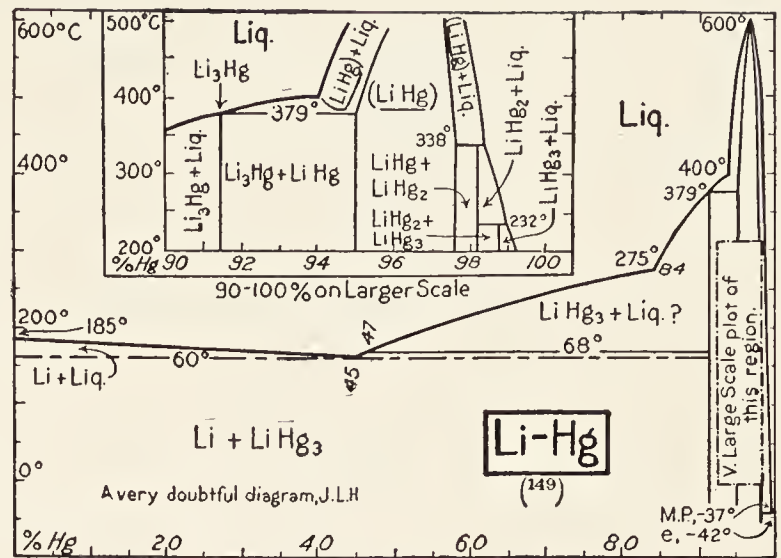
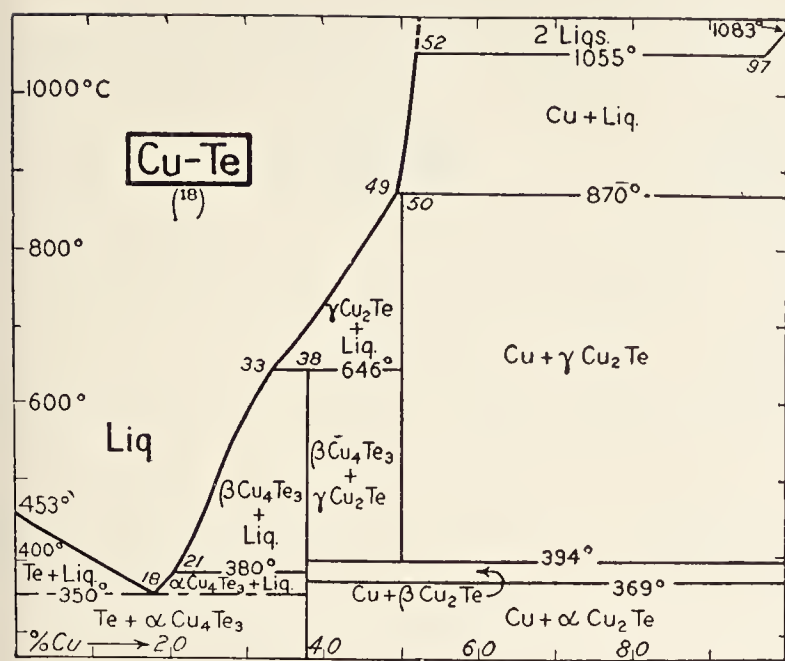






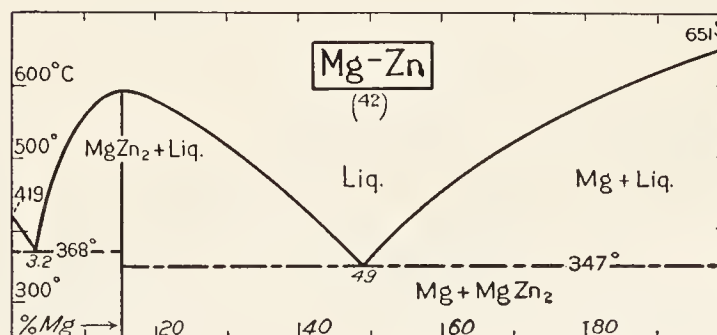
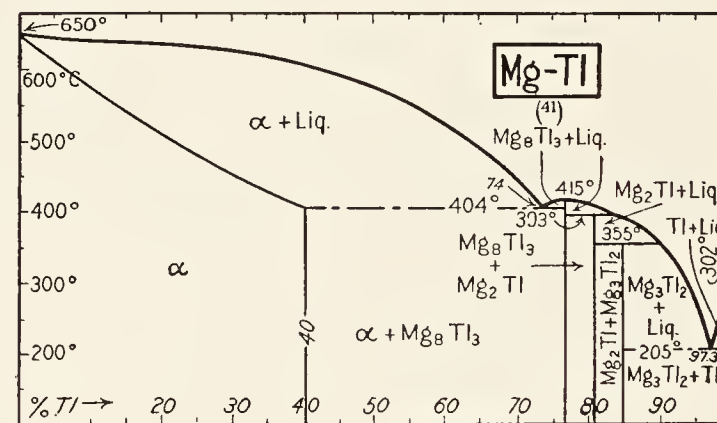
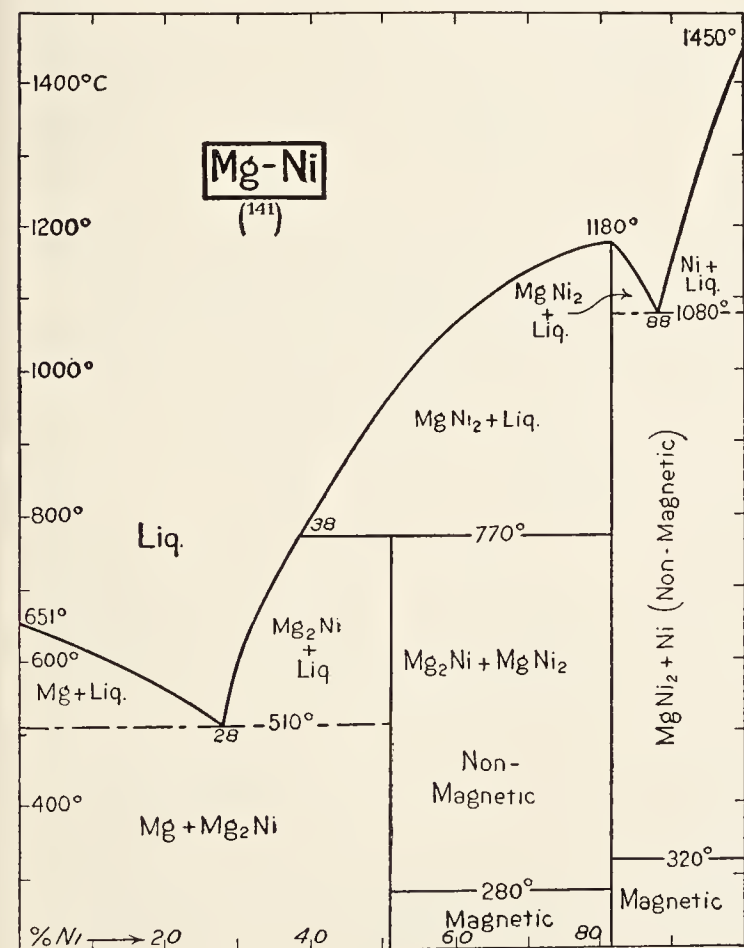
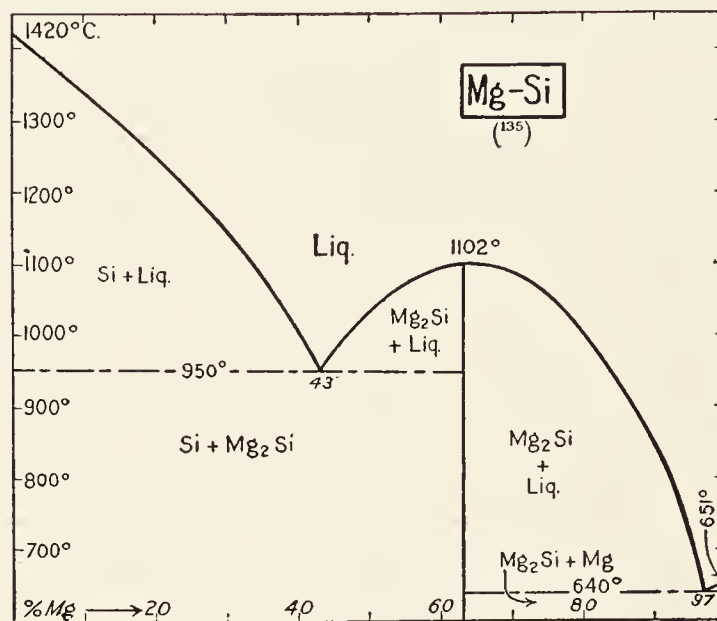
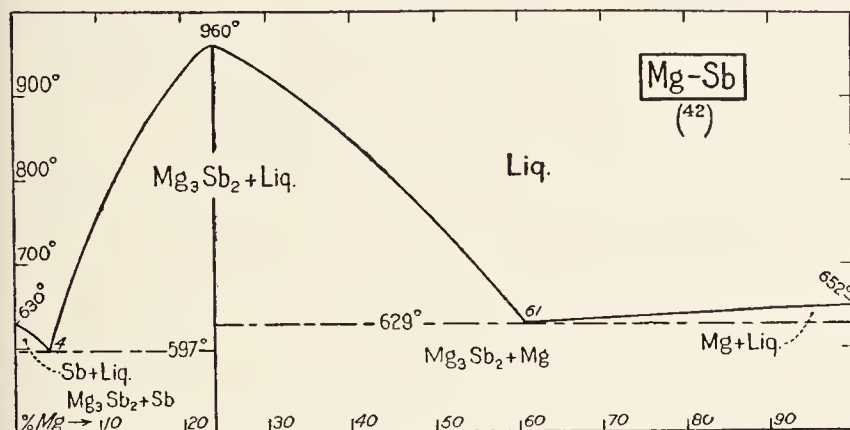
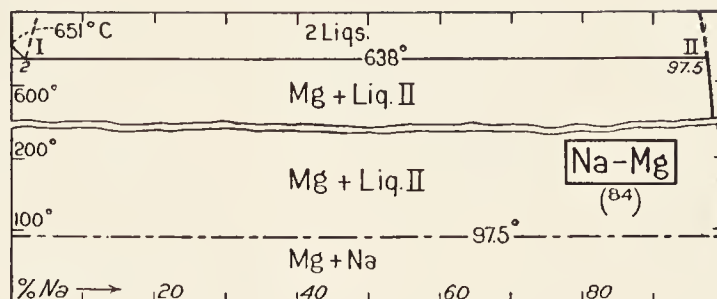
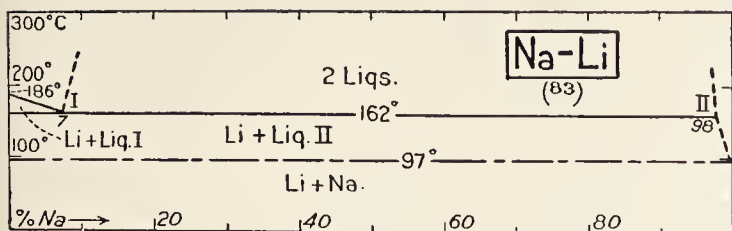


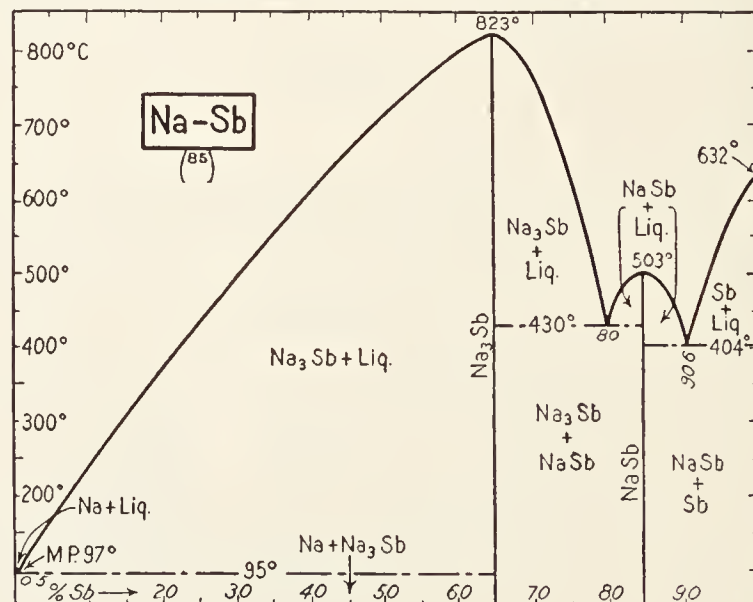
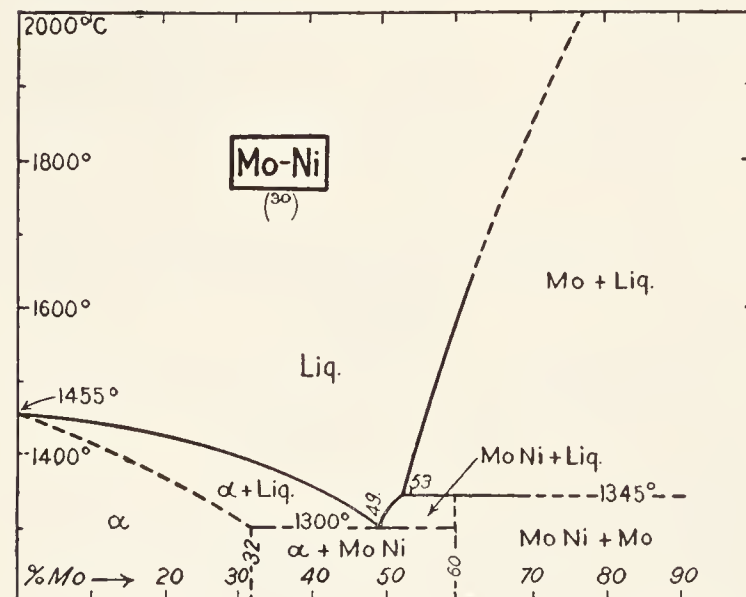
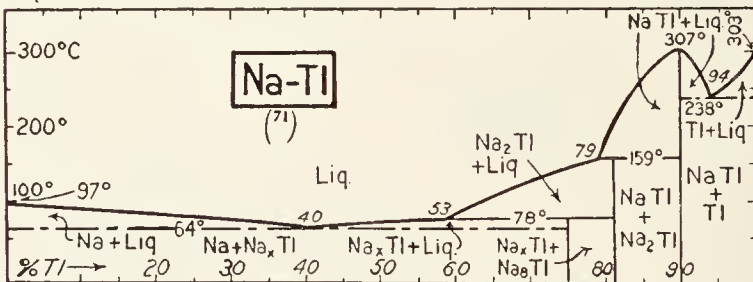
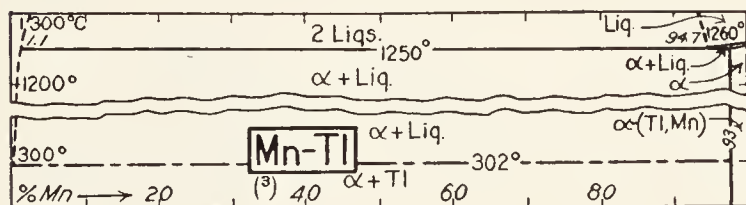
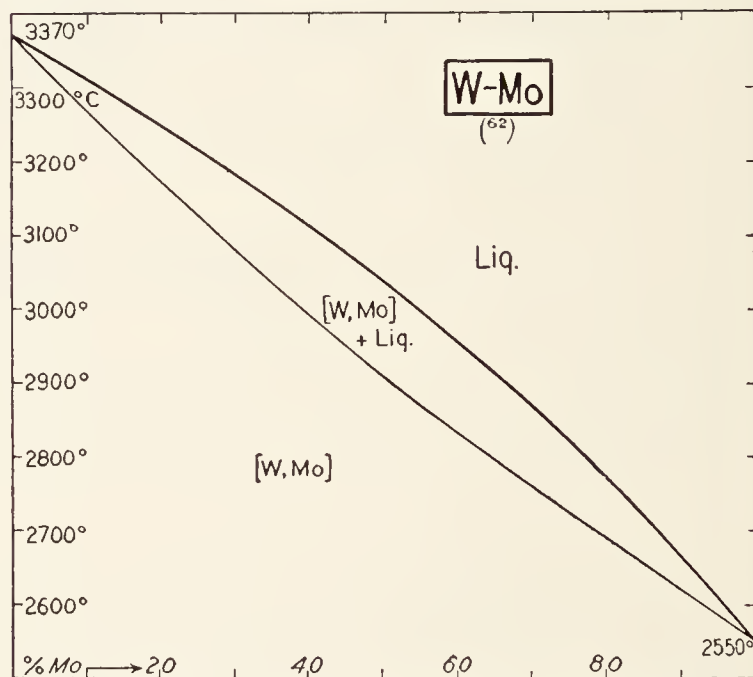
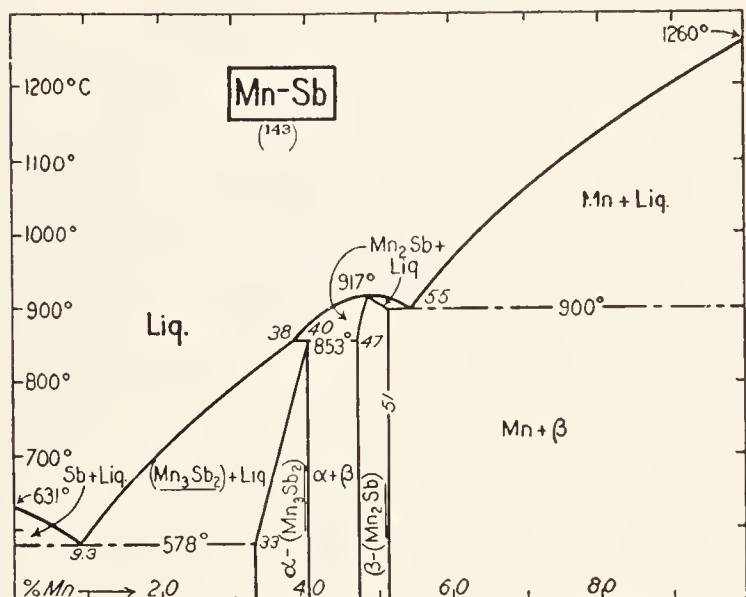
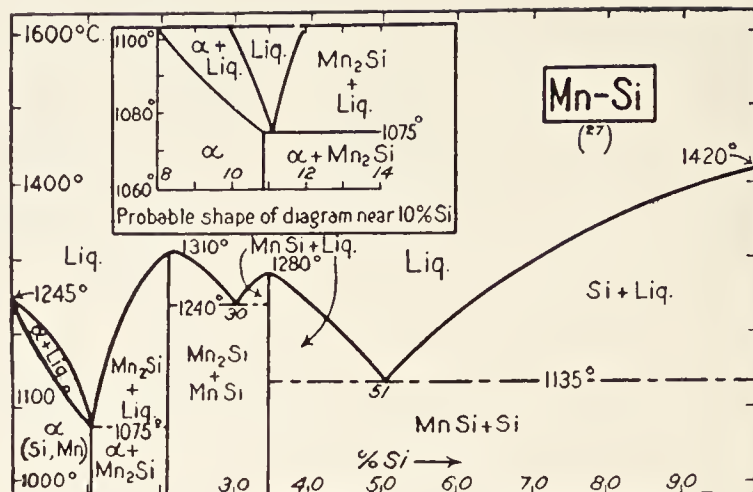
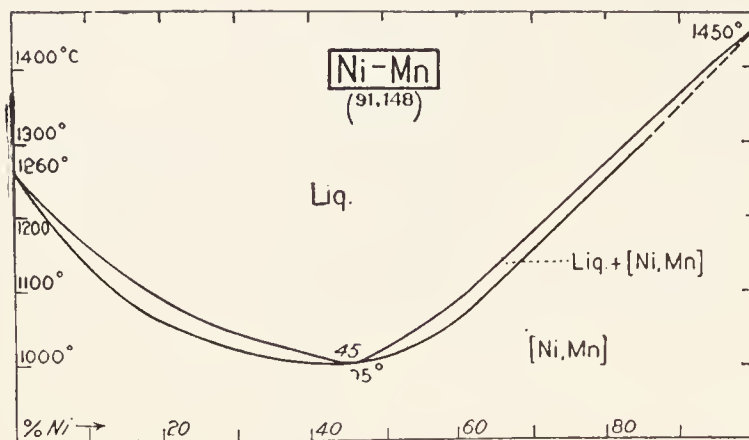




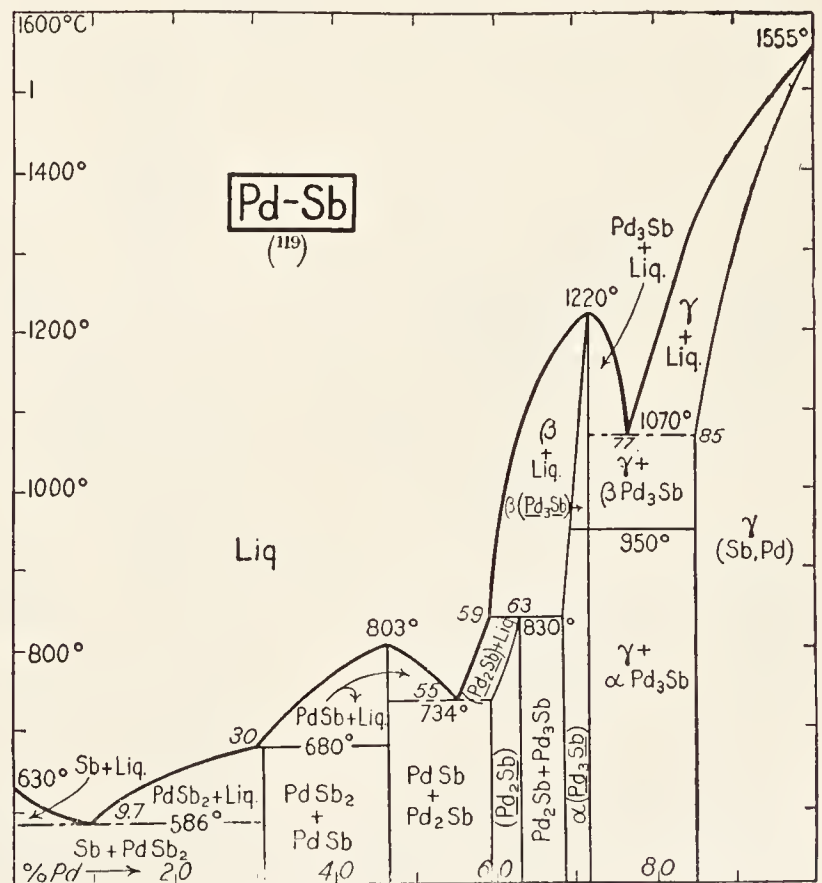
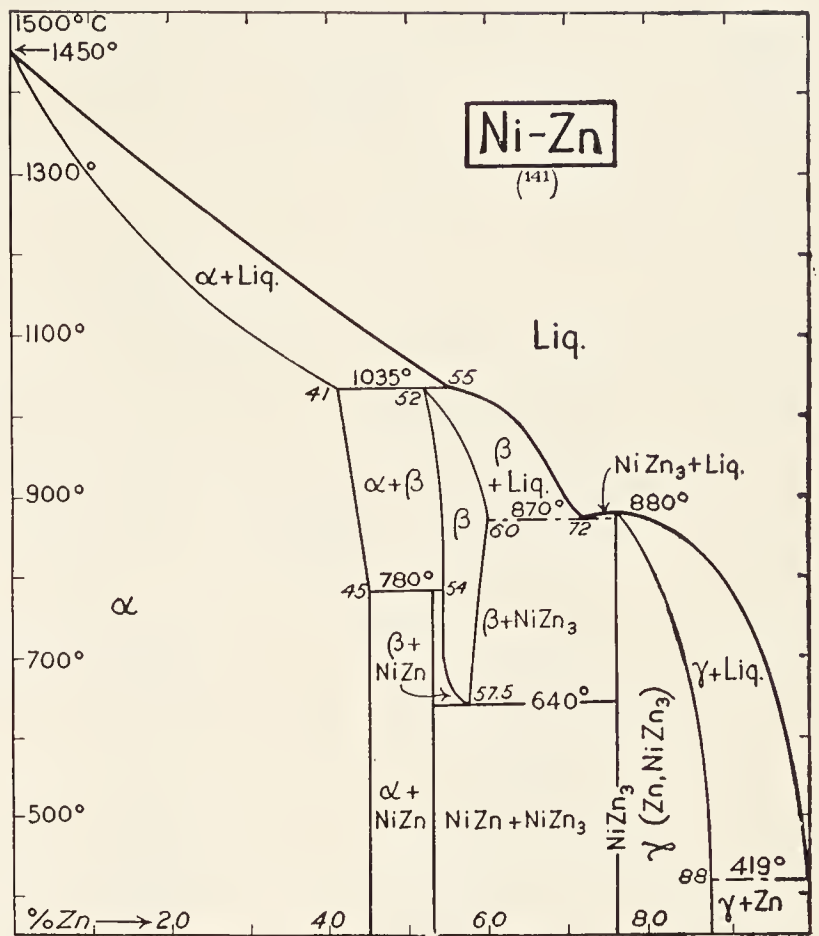
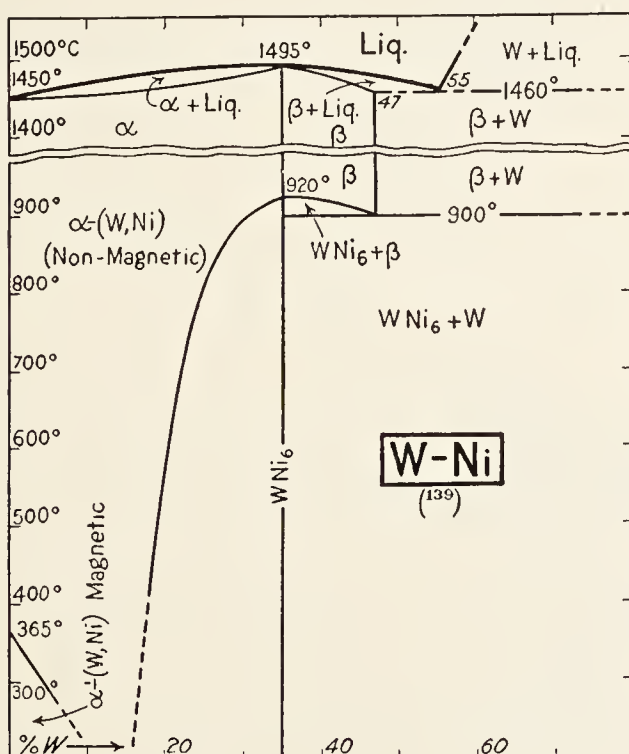
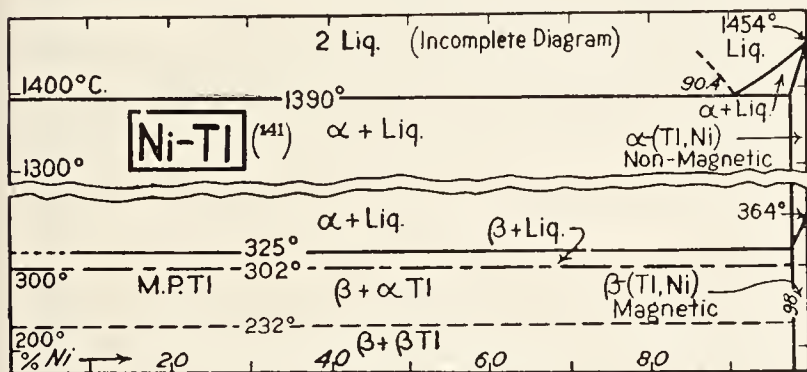
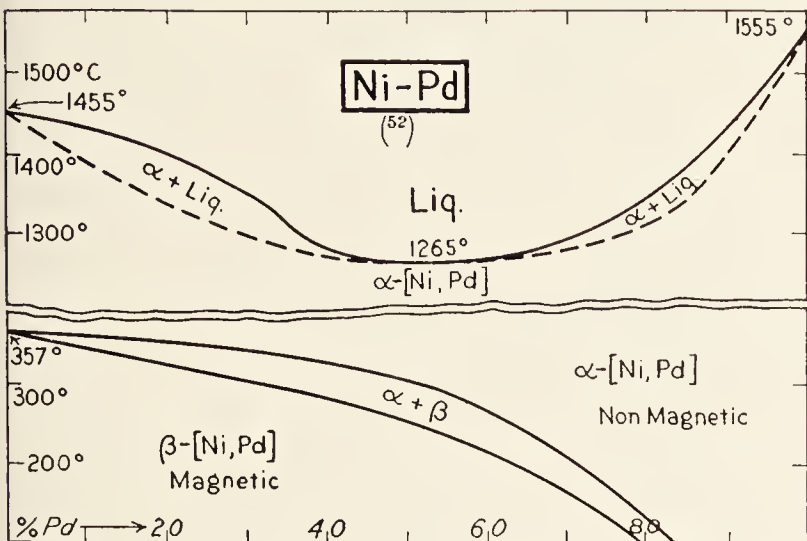
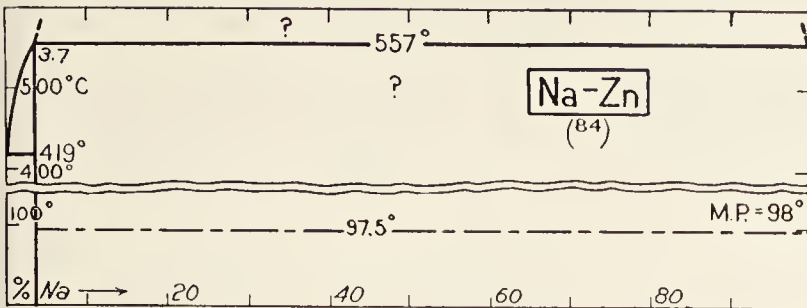


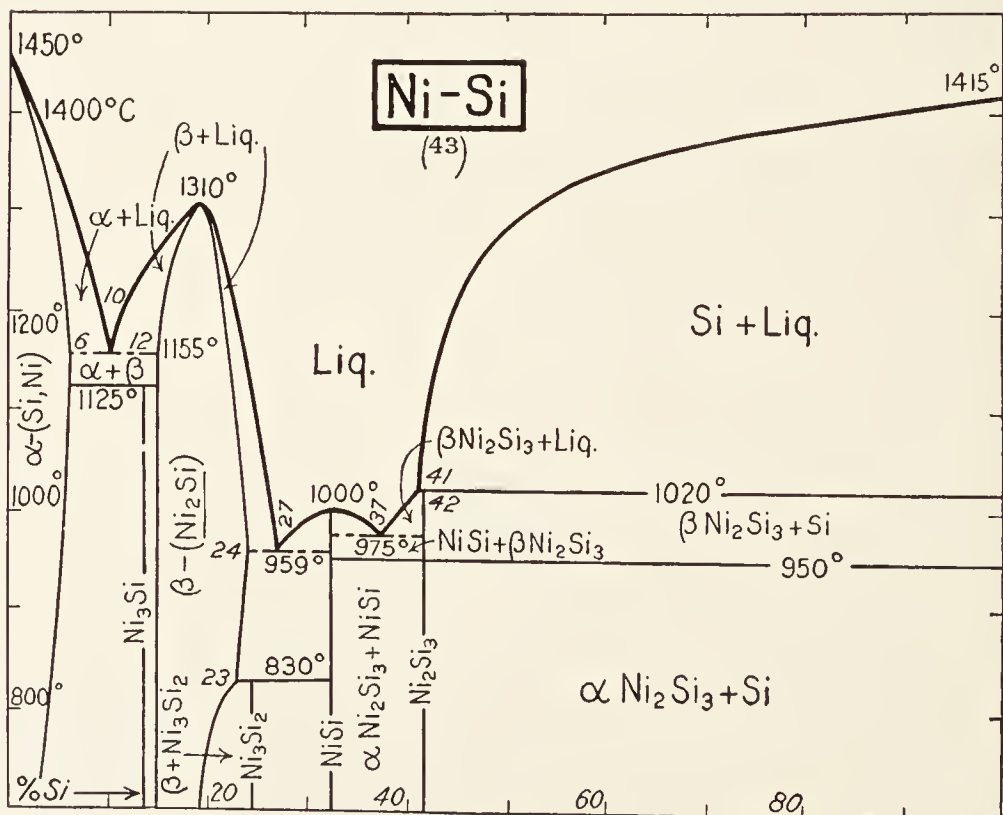
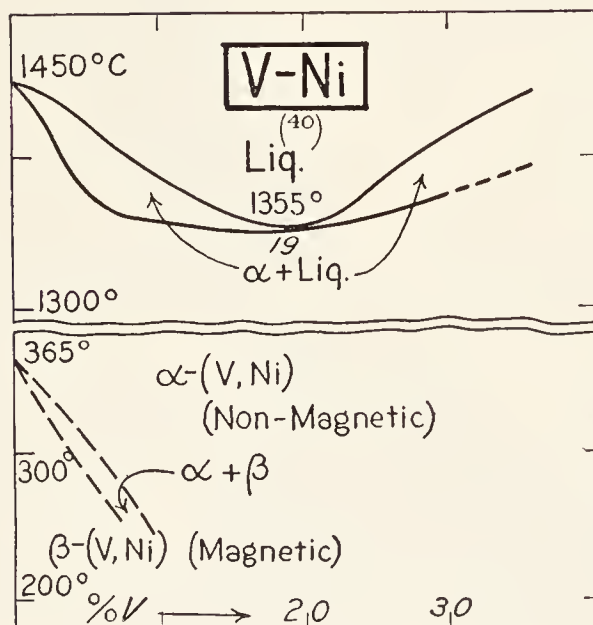
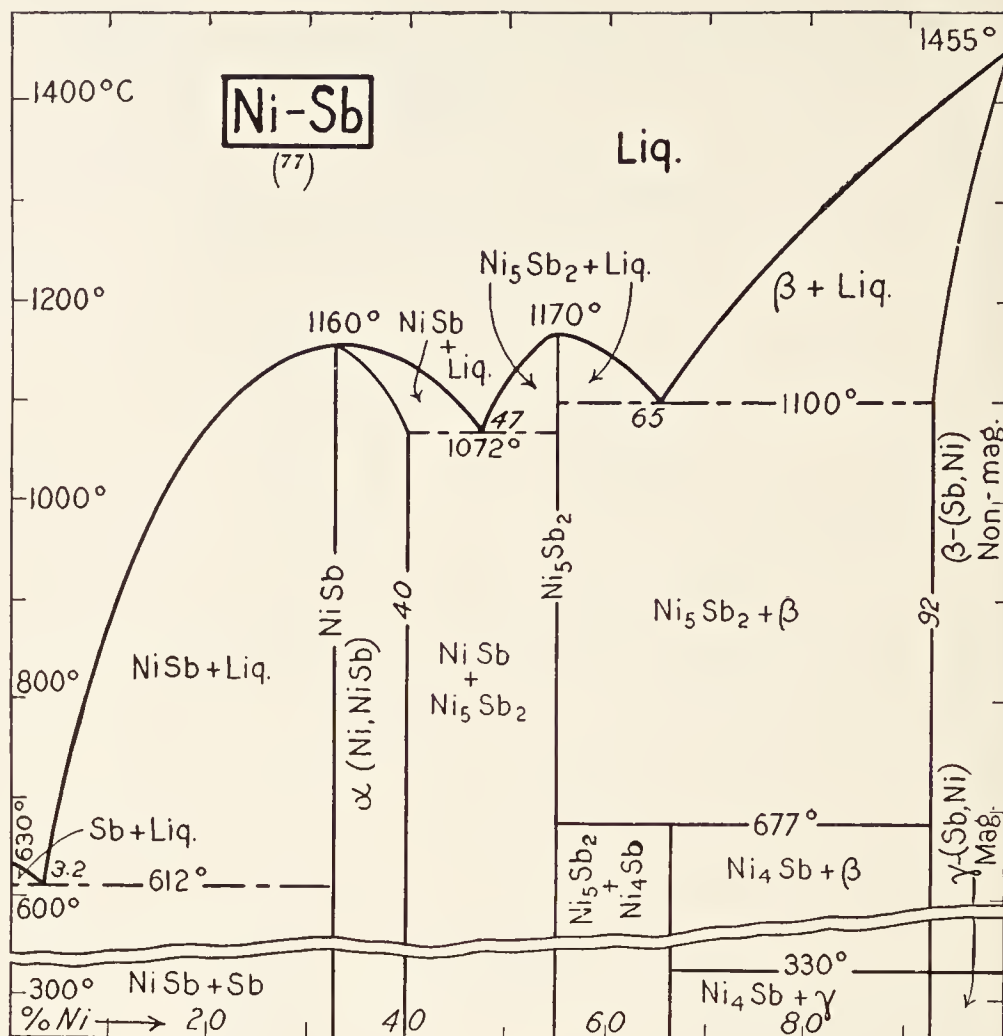
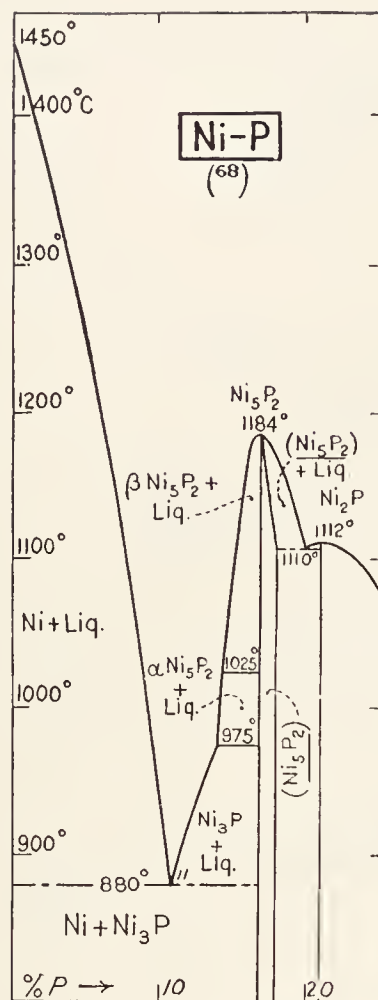




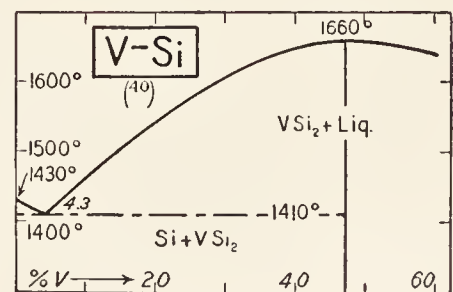
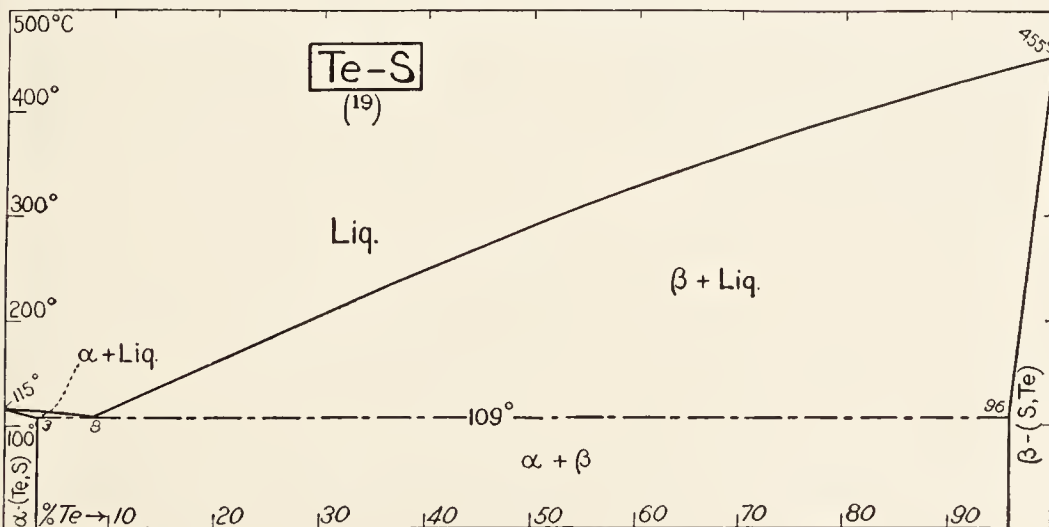
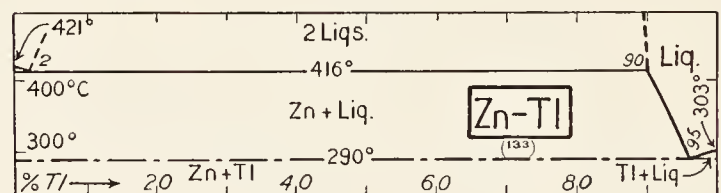
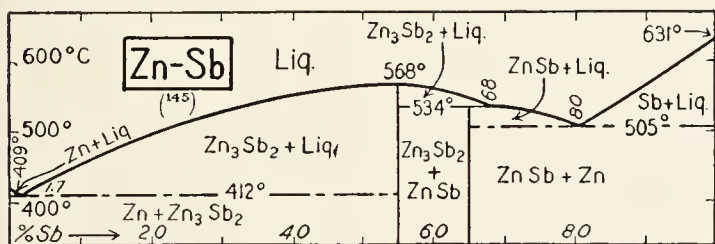
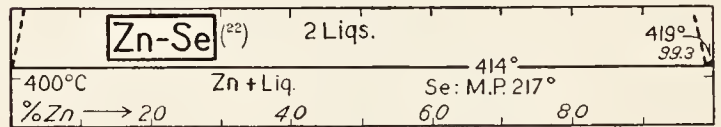
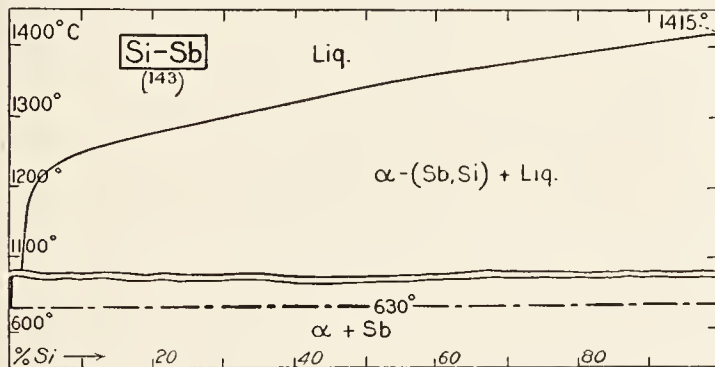
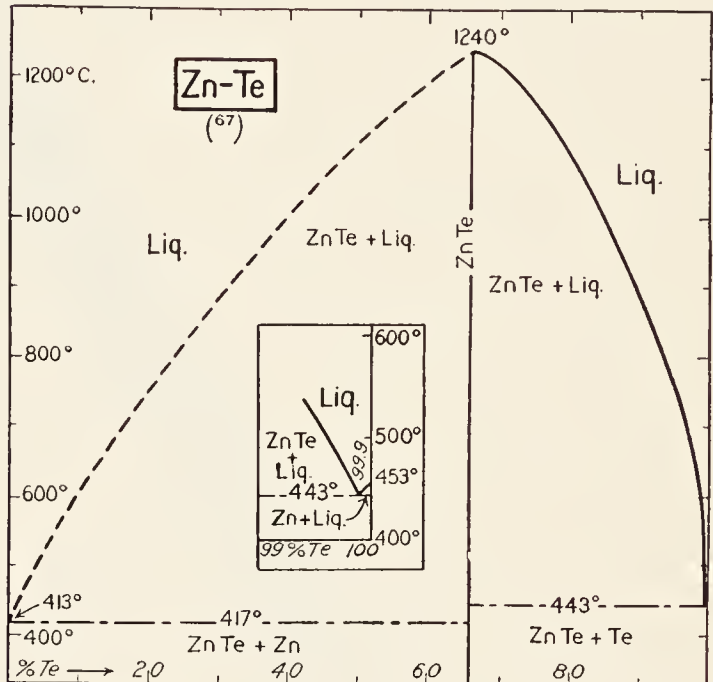
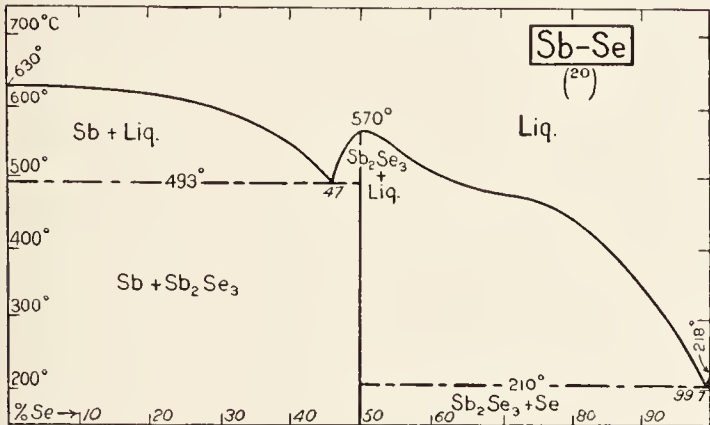
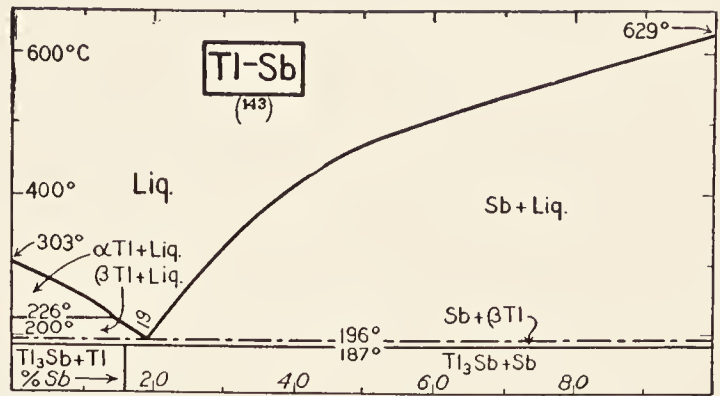
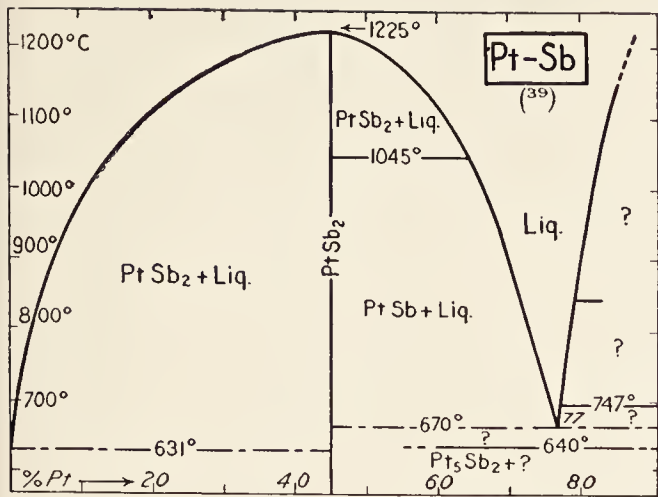


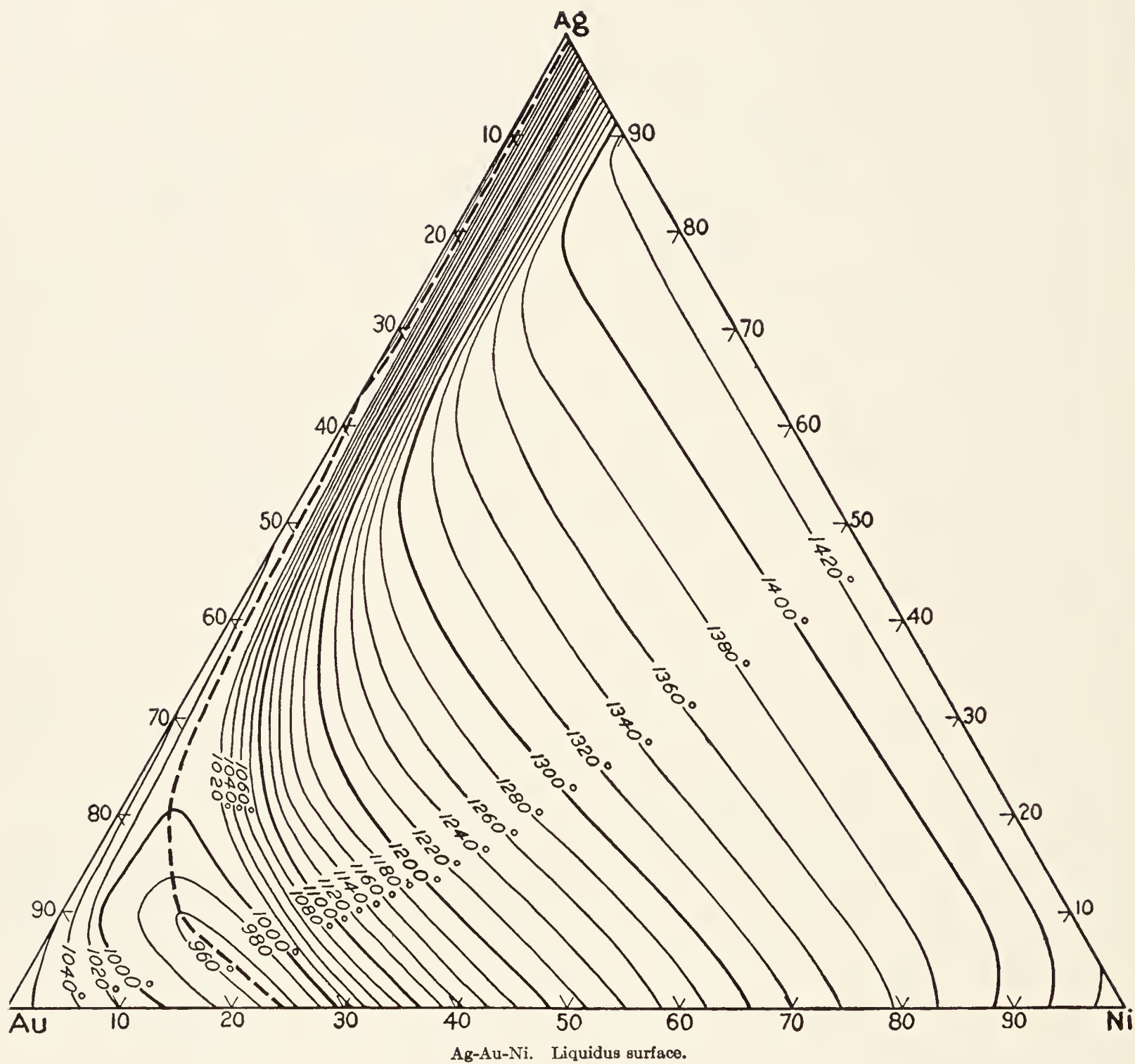




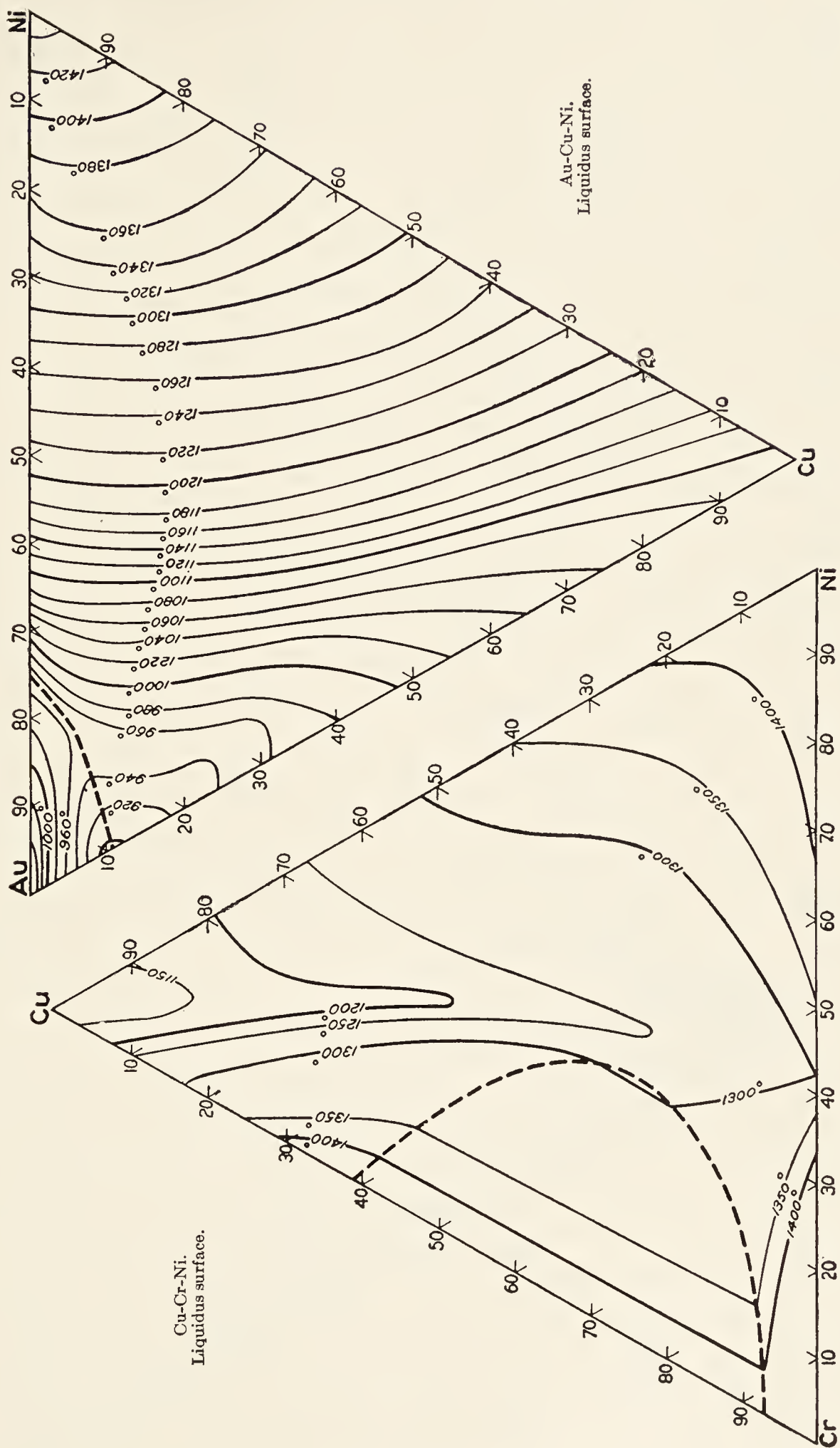


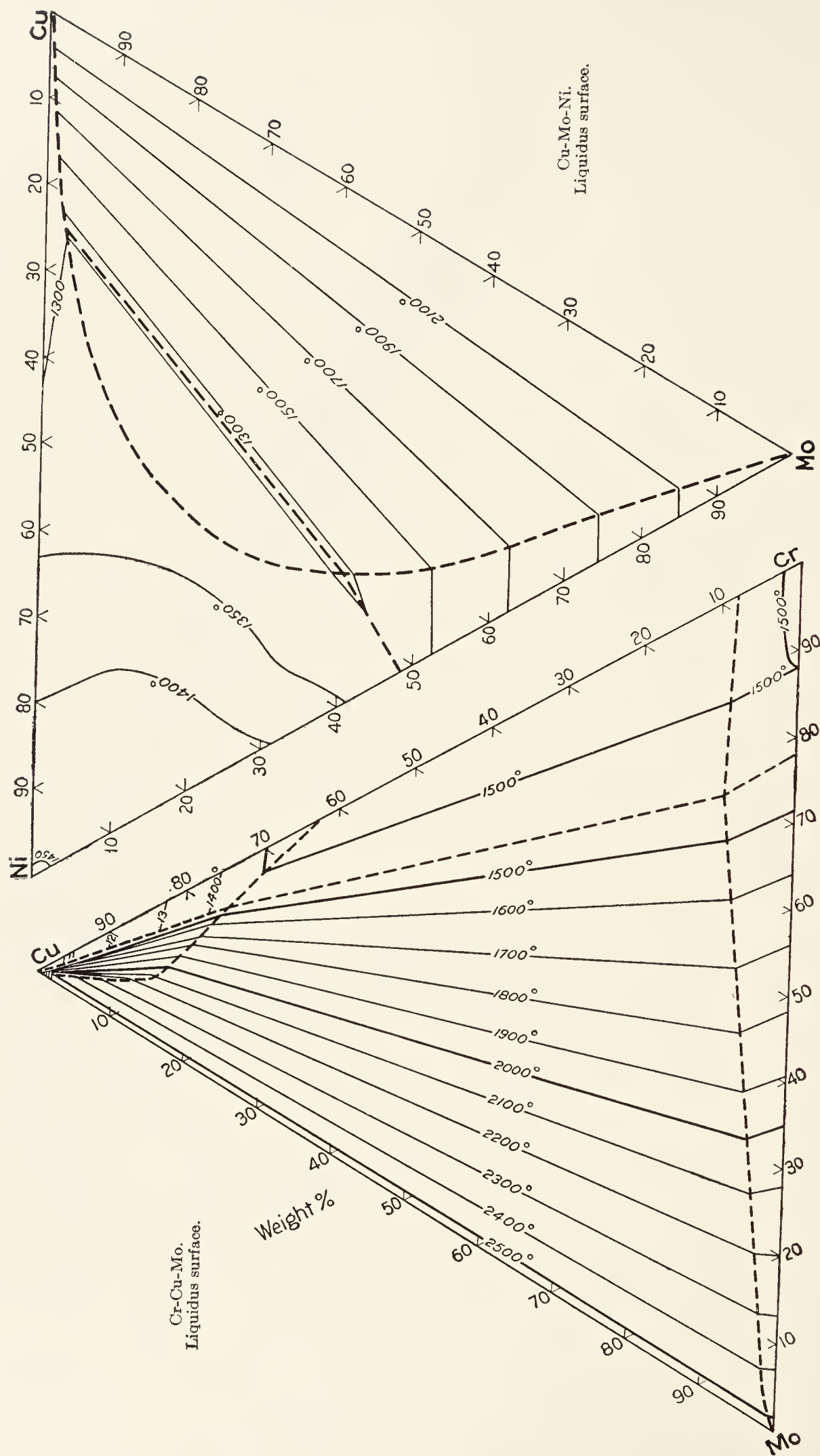




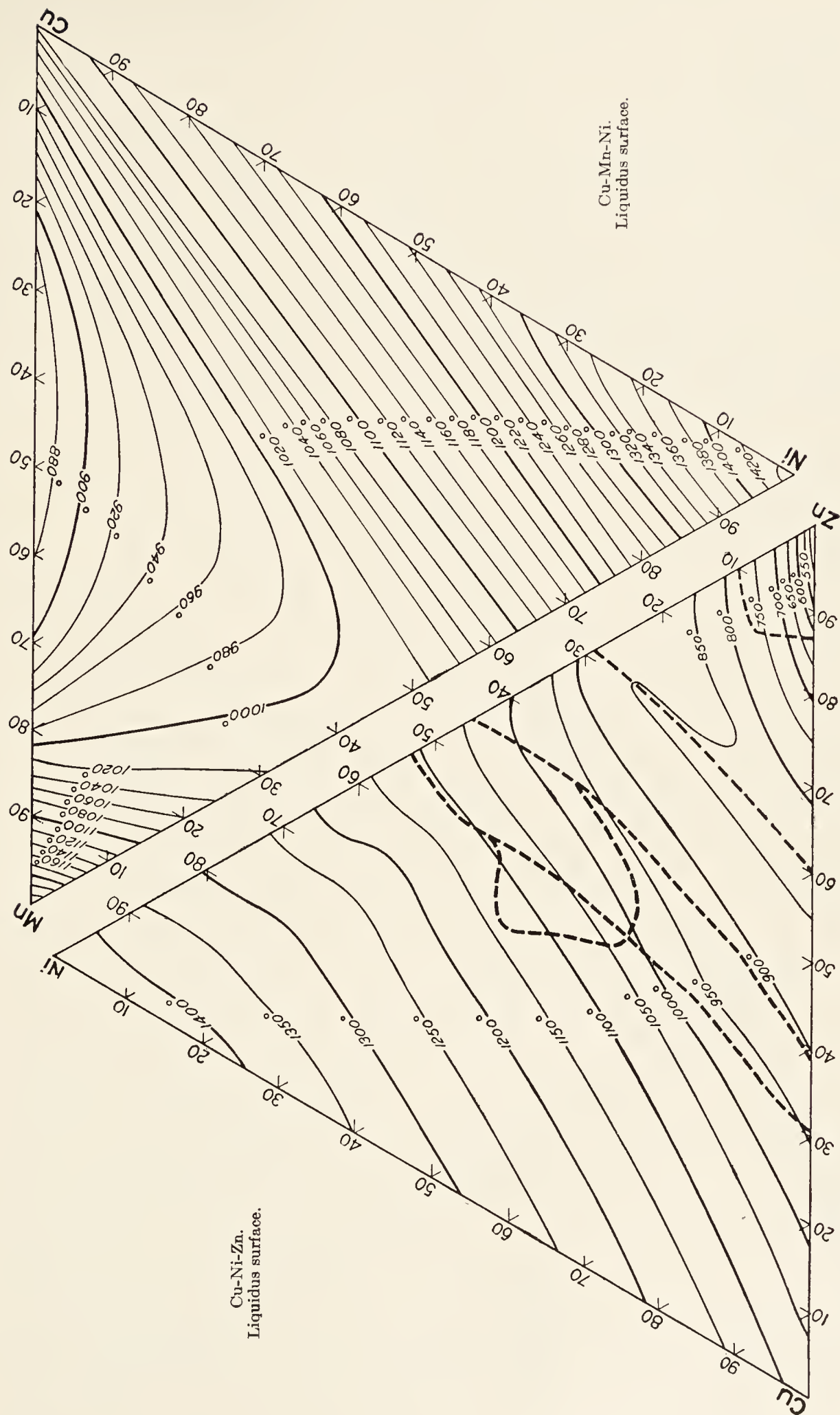


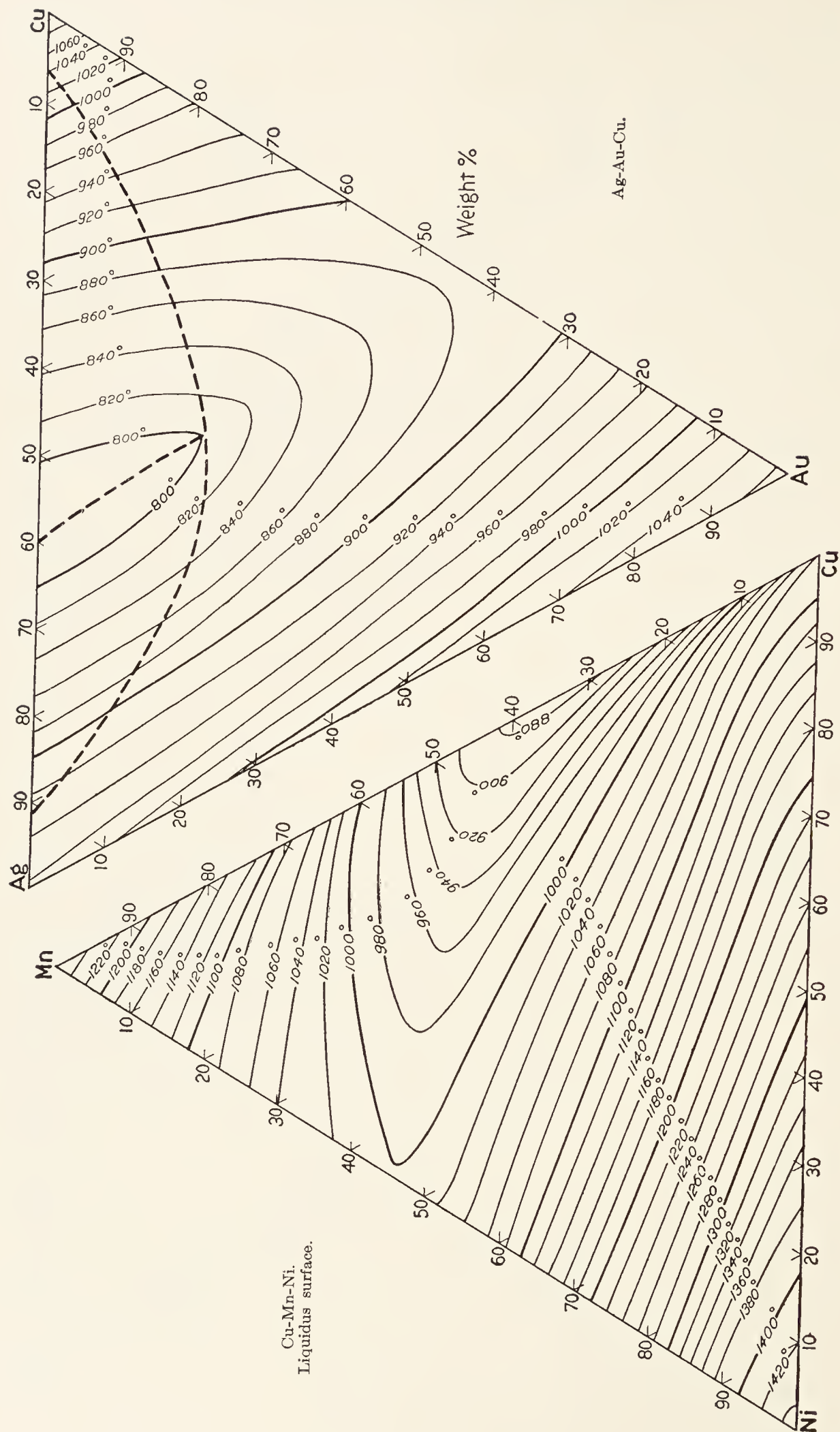




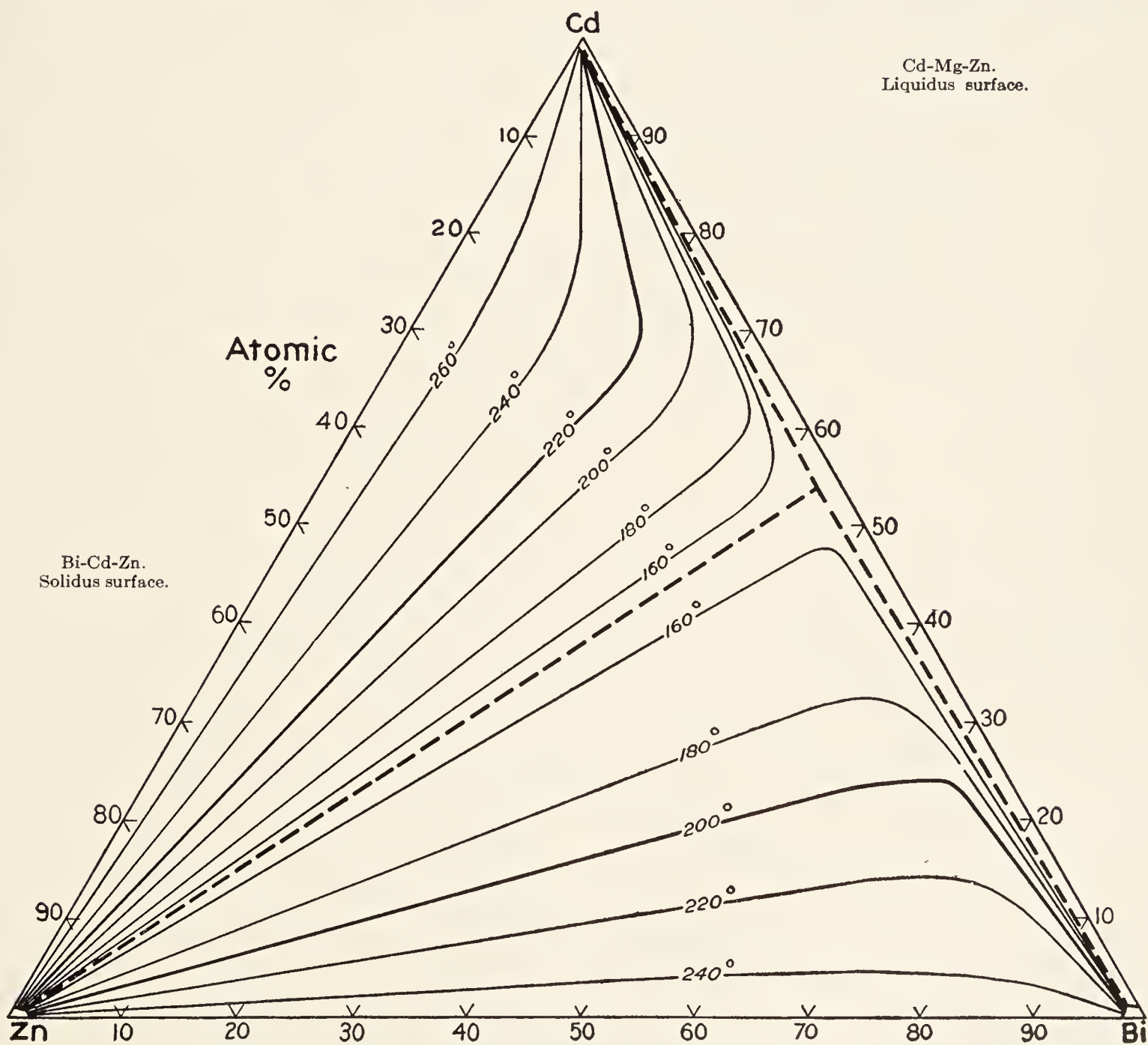
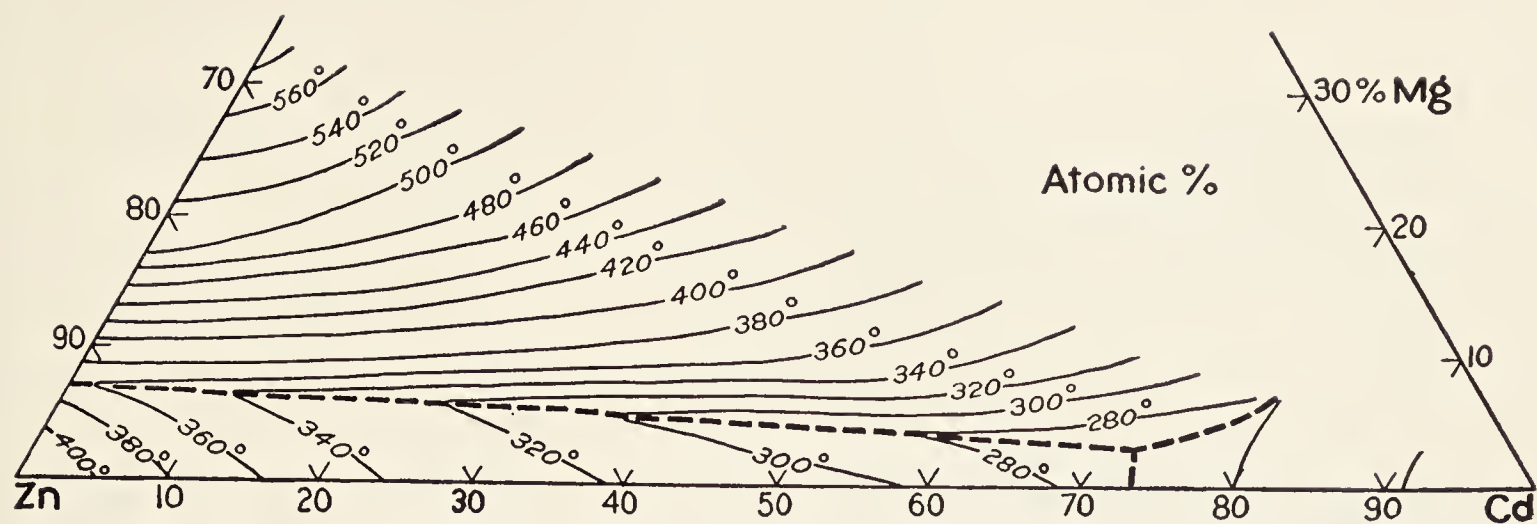


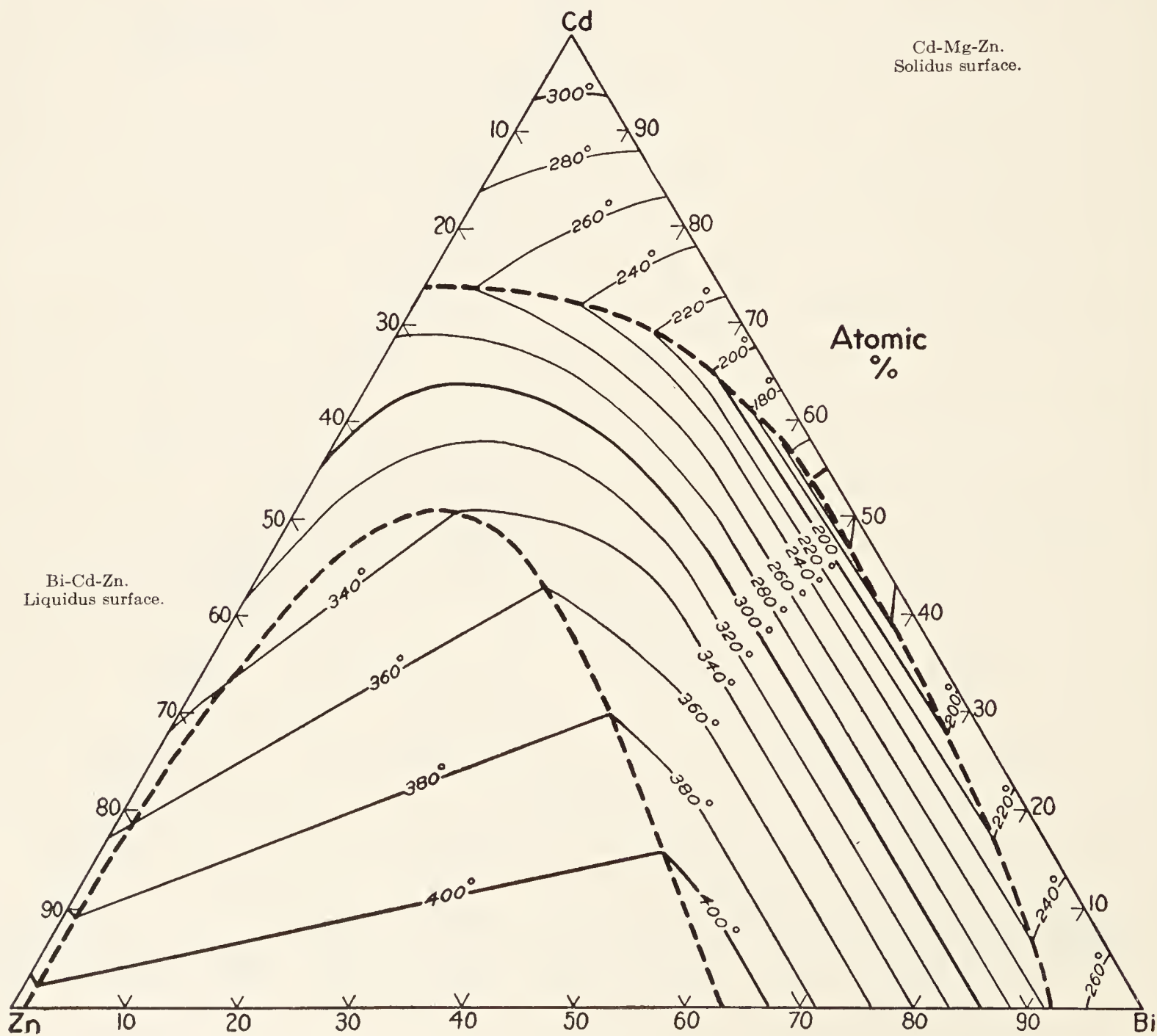
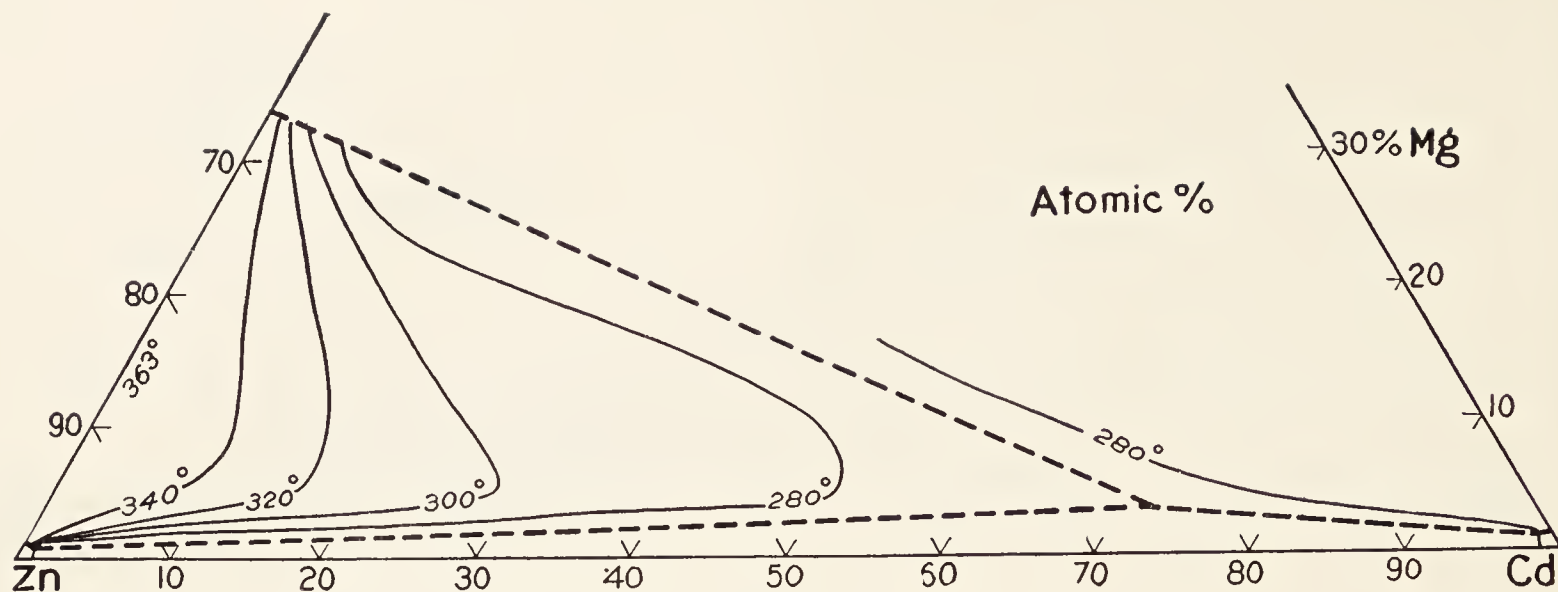














## FERROUS ALLOYS

C. H. DESCH

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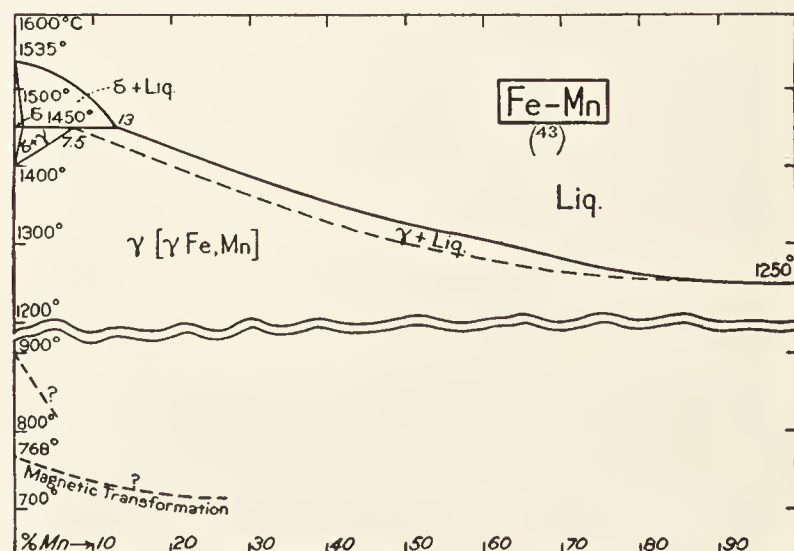
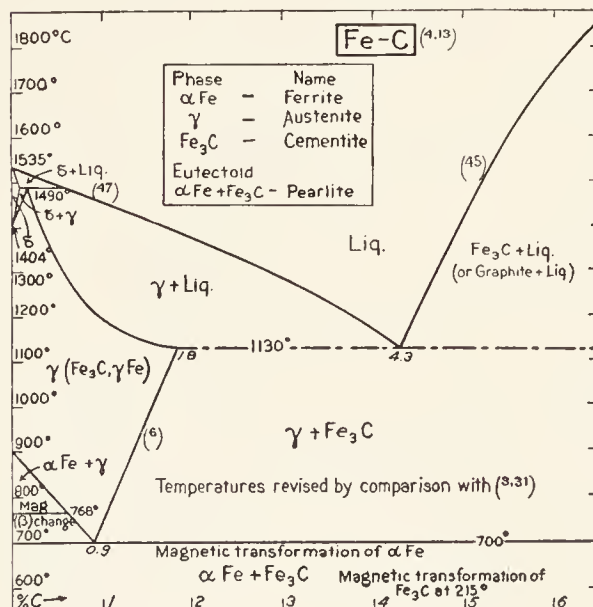
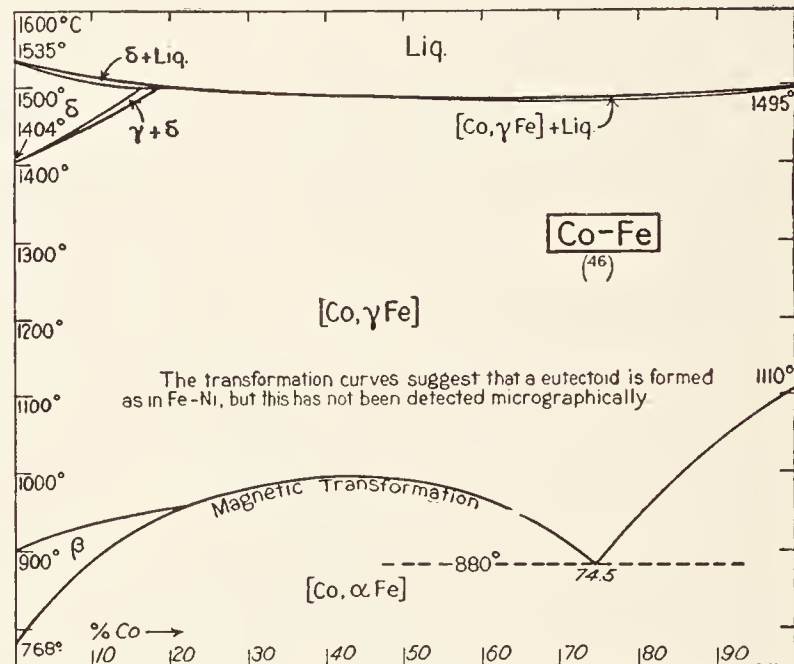
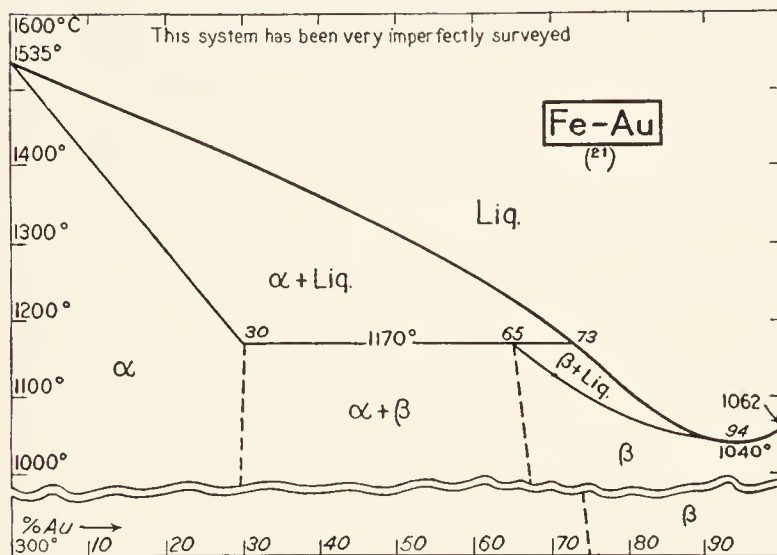
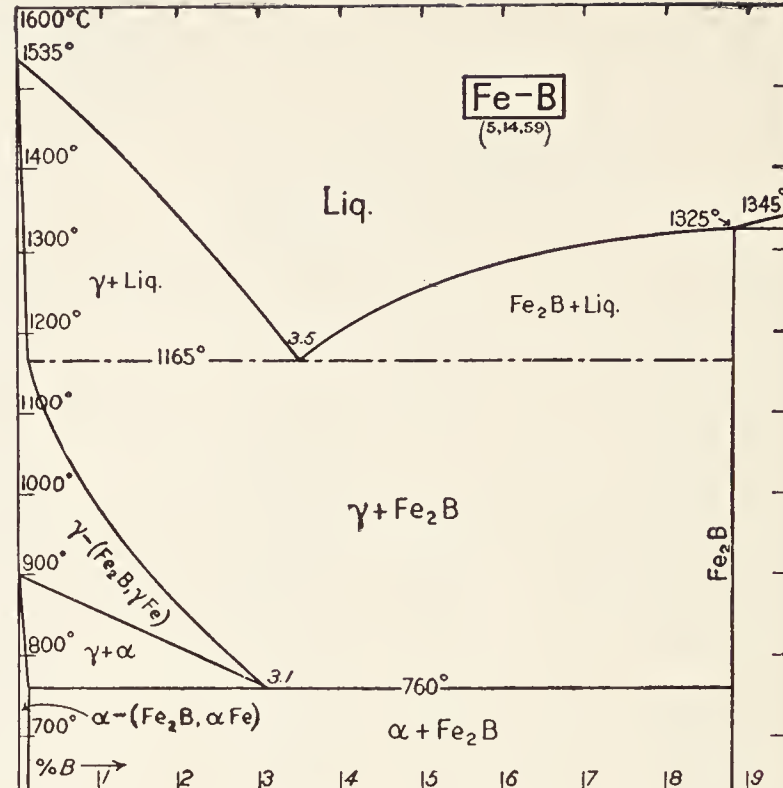
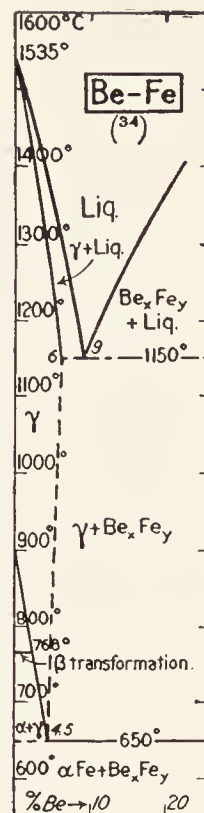
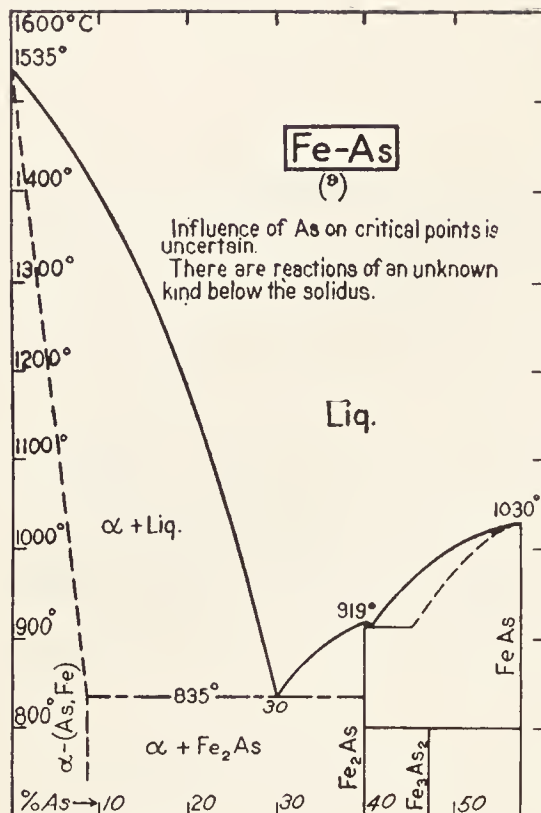
\* Two immiscible liquid phases.

## LITERATURE

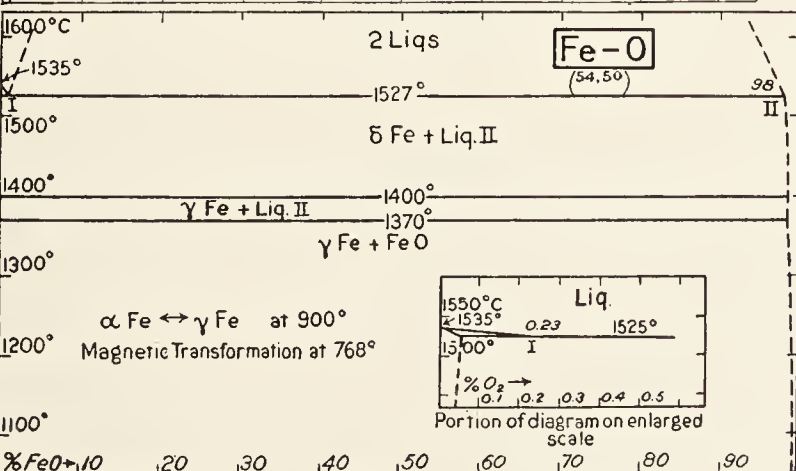
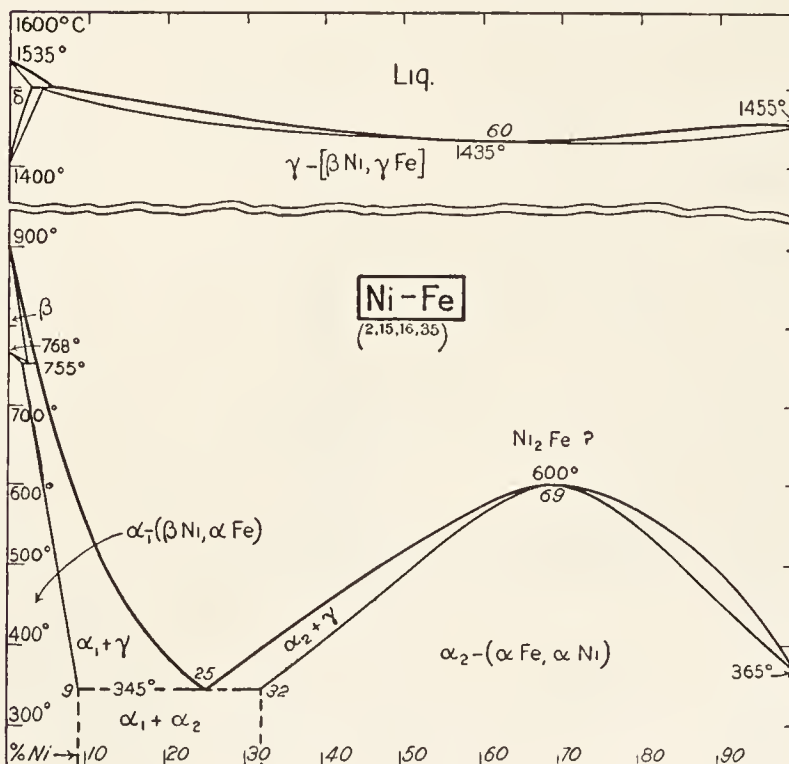
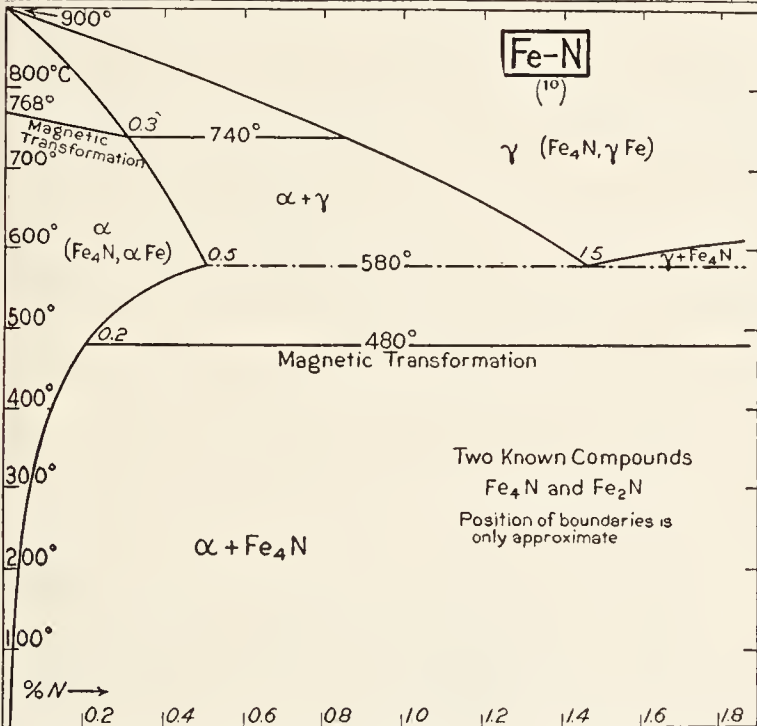
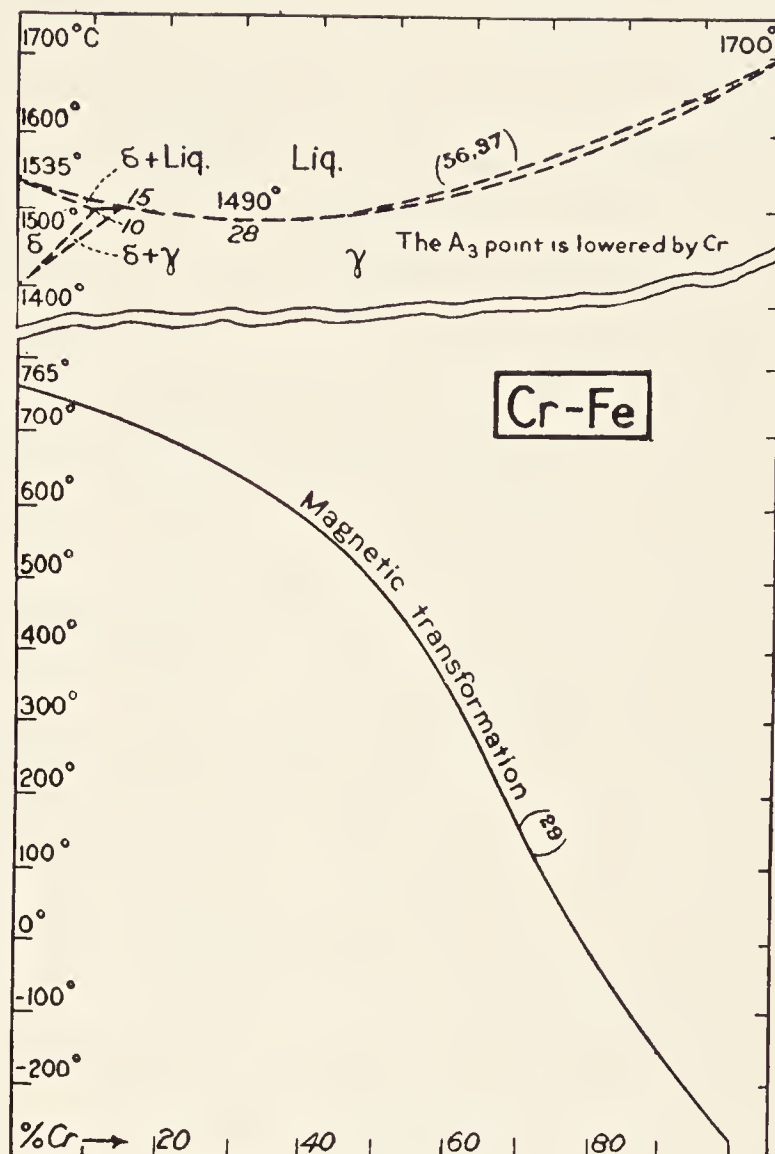
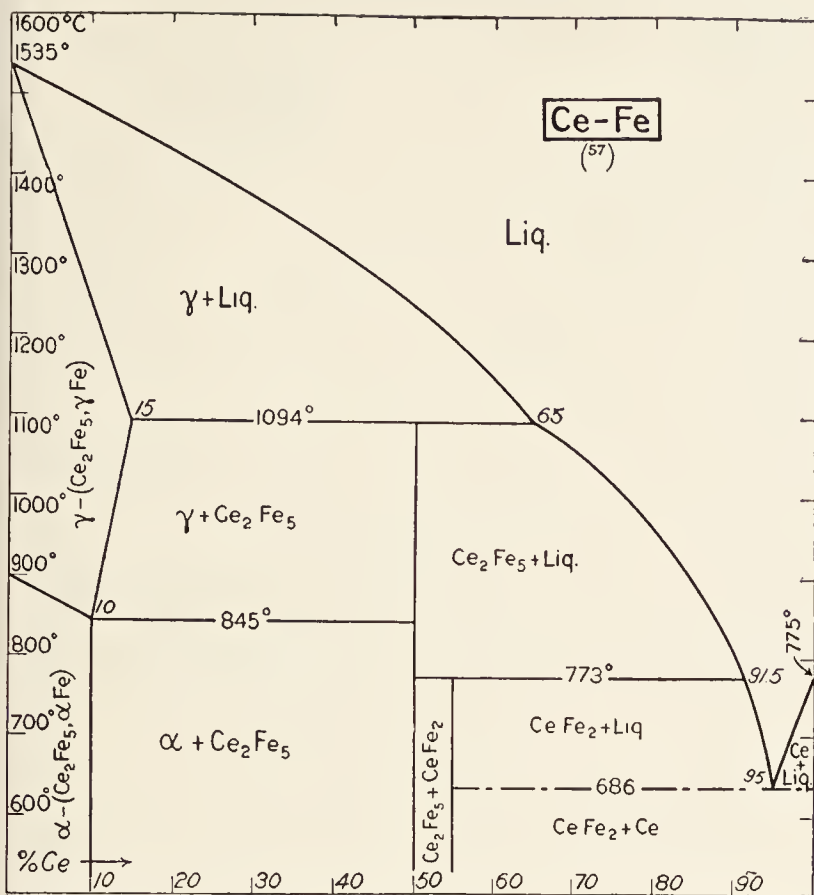
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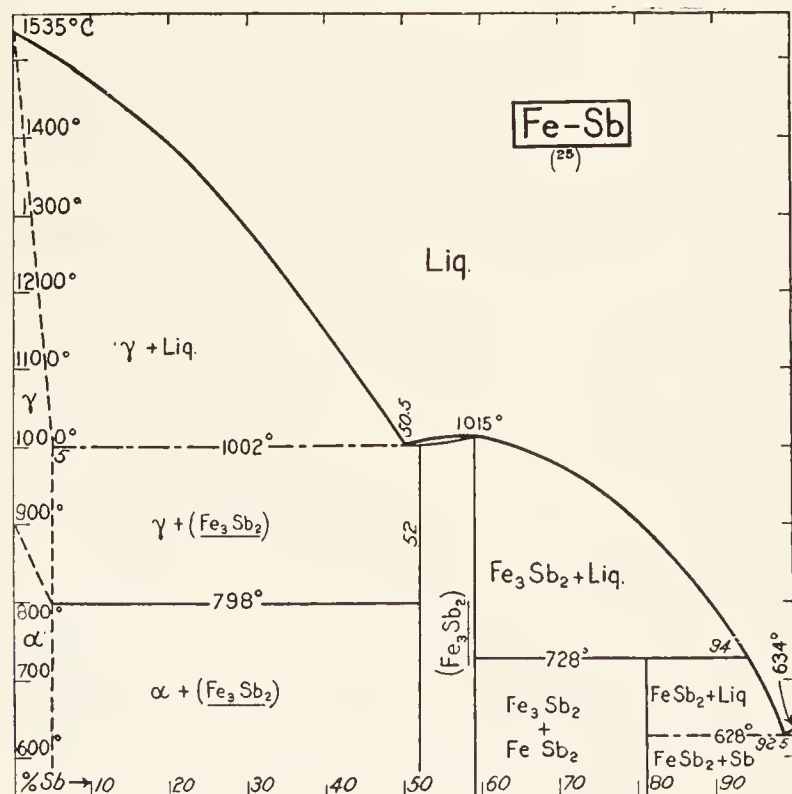
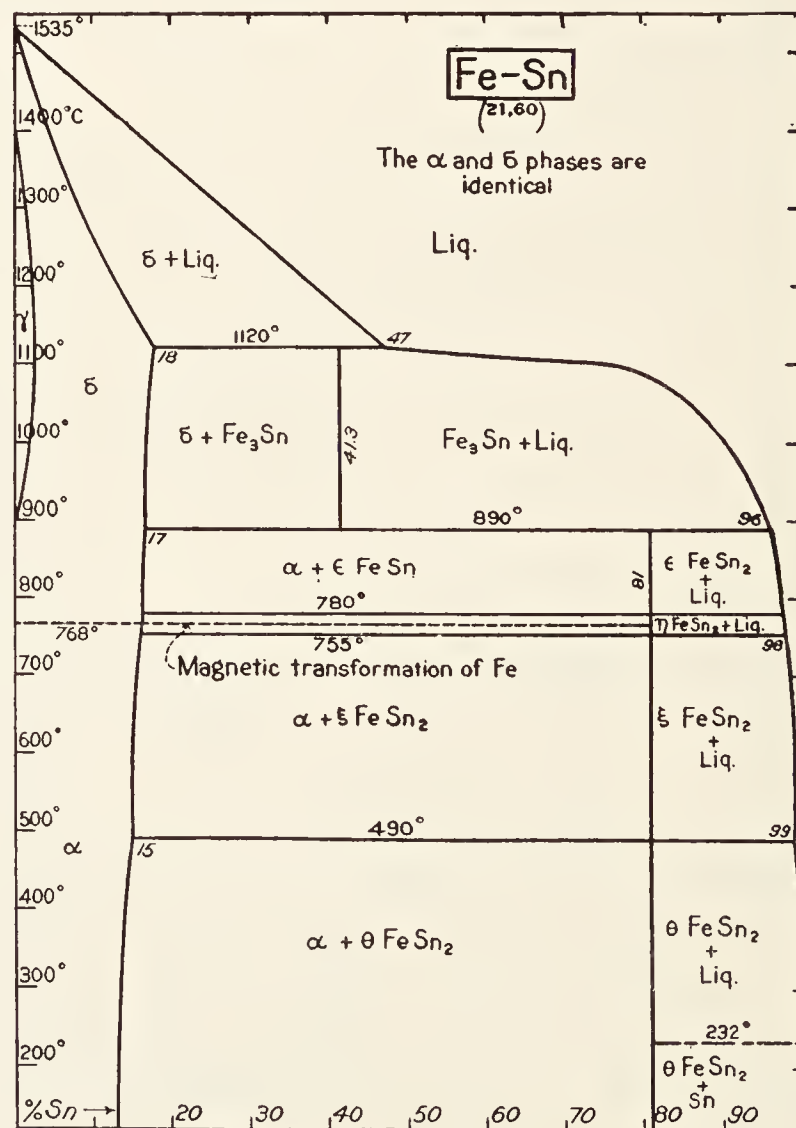
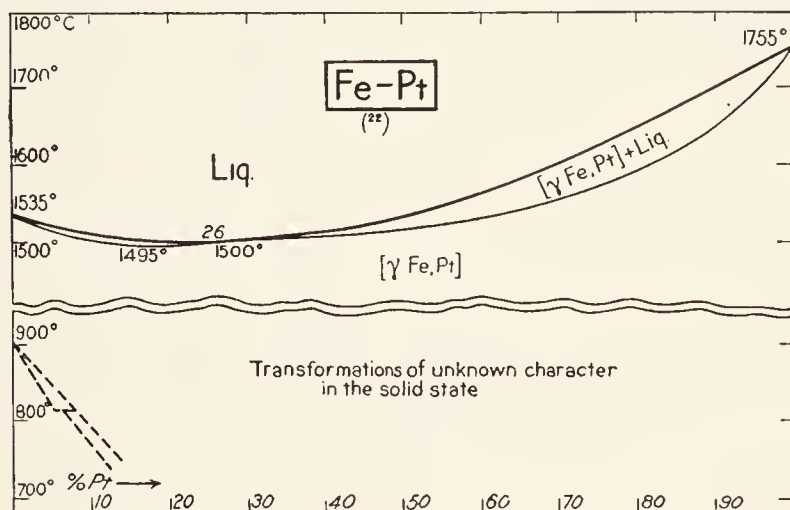
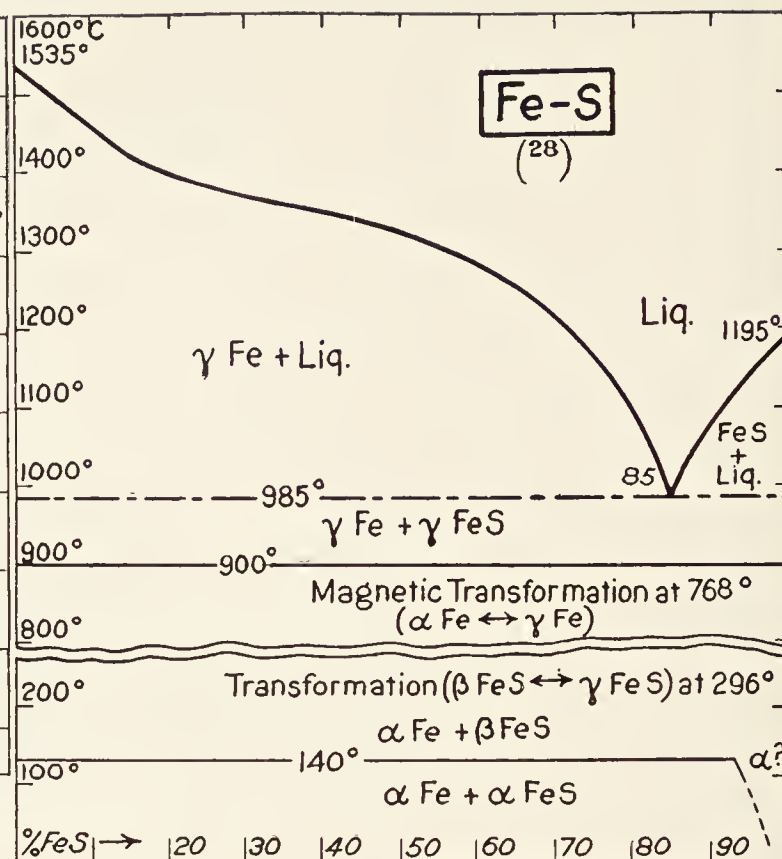
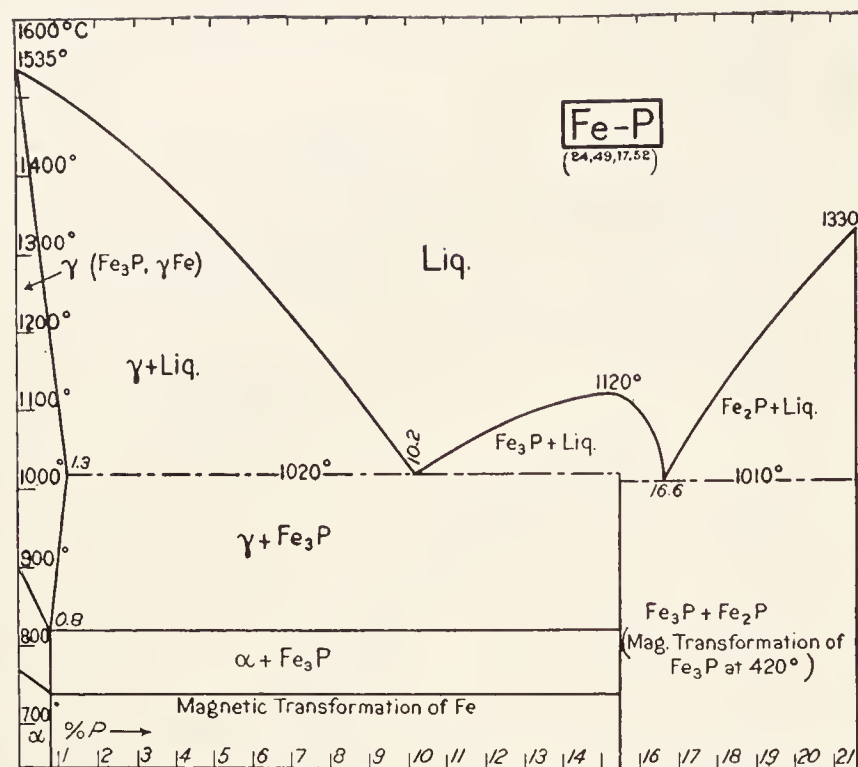
(1) Banberger, Einerl and Nussbaum, 77, 45: 141; 25. (2) Benedicks, 55, 7: 290; 11. (3) Bureau of Standards, Washington, D. C., O. (4) Carpenter

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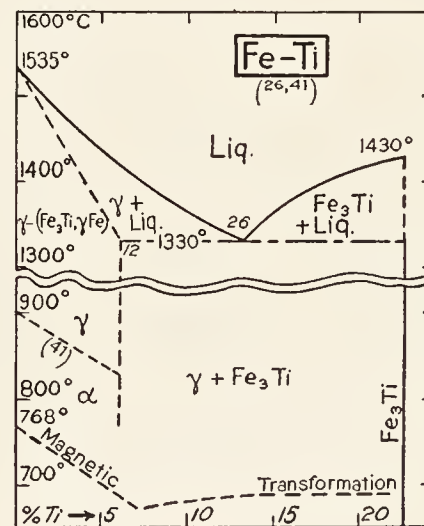
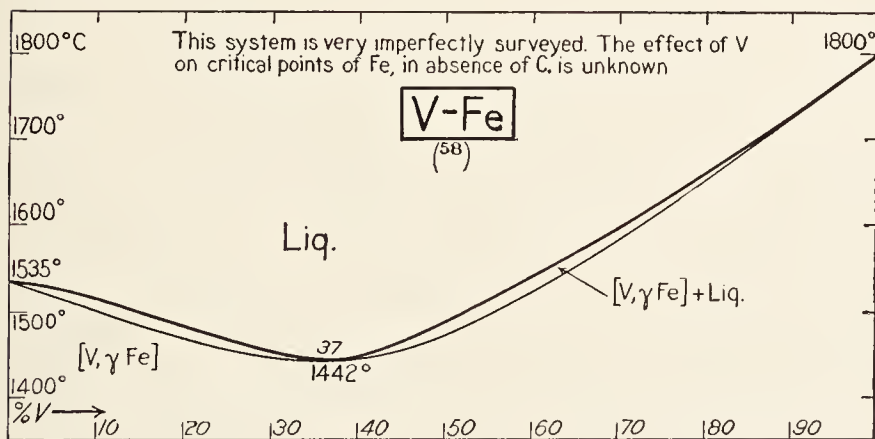
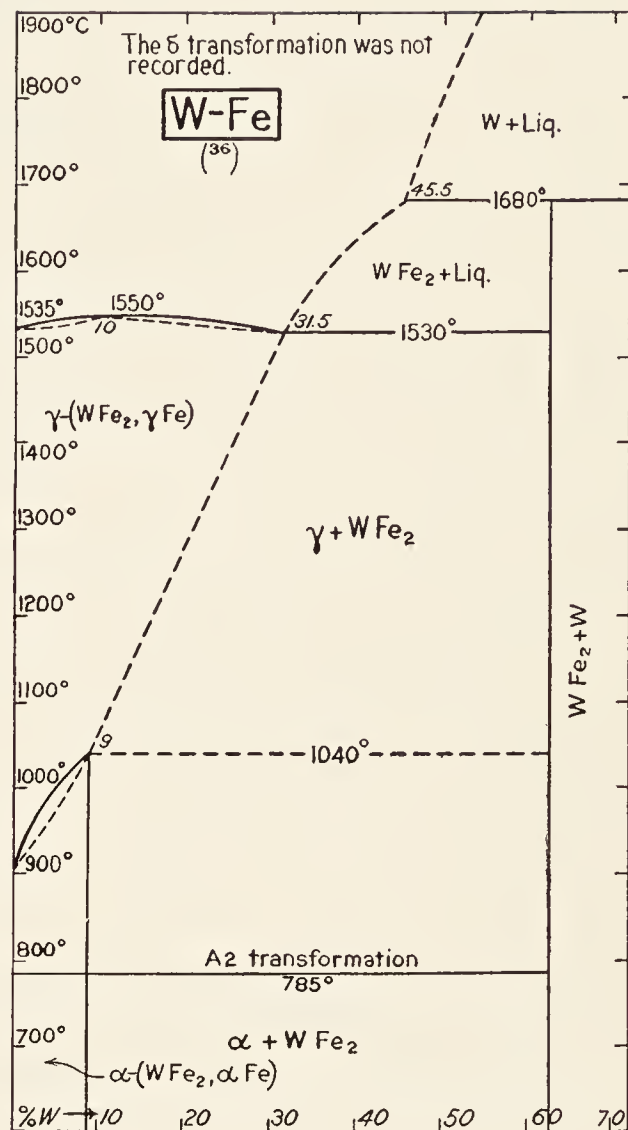
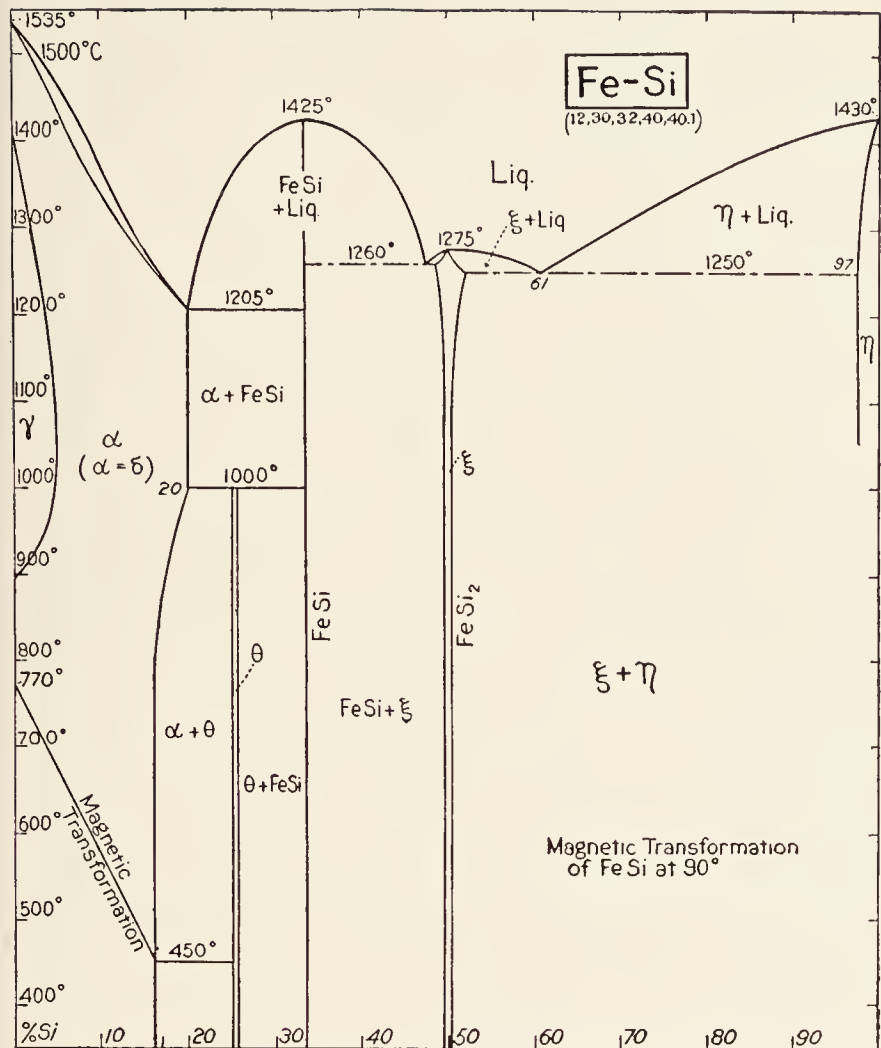


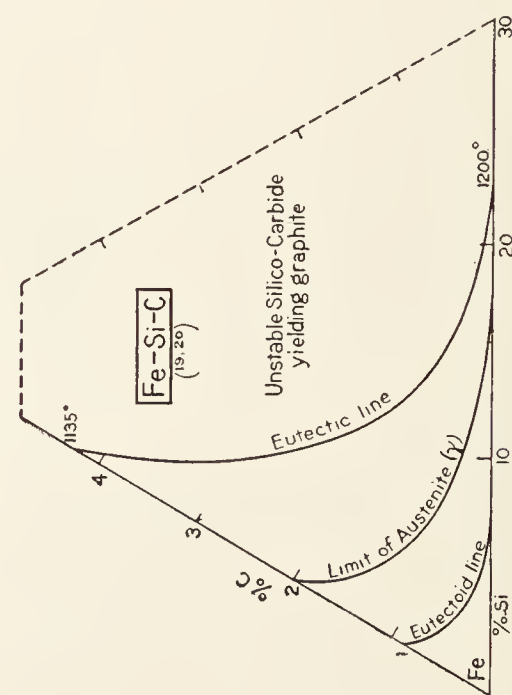
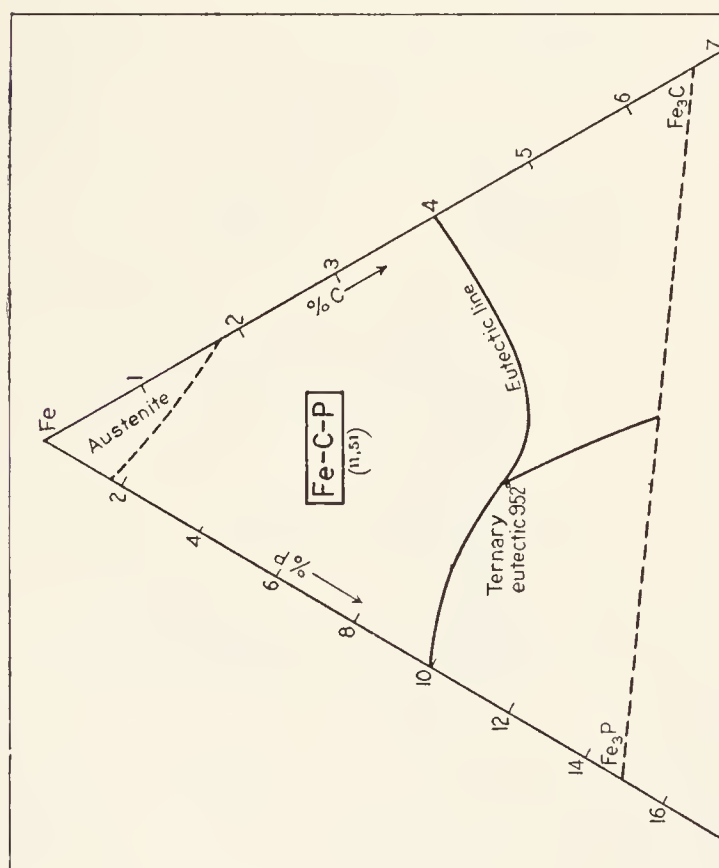
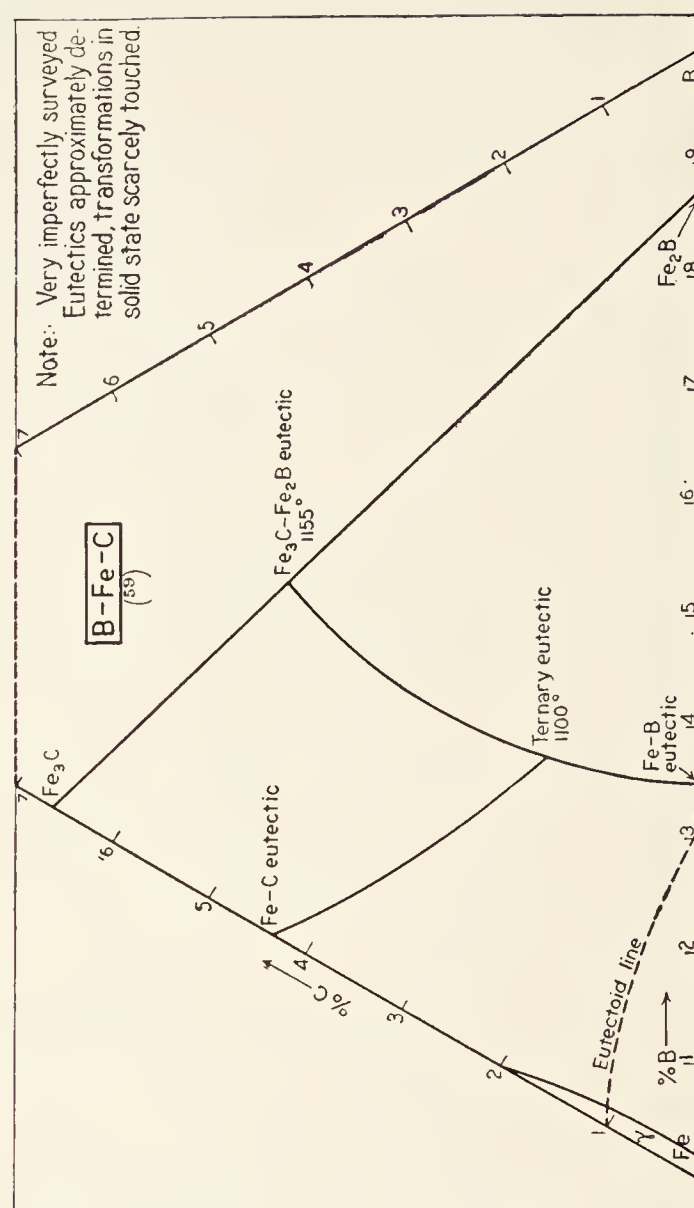
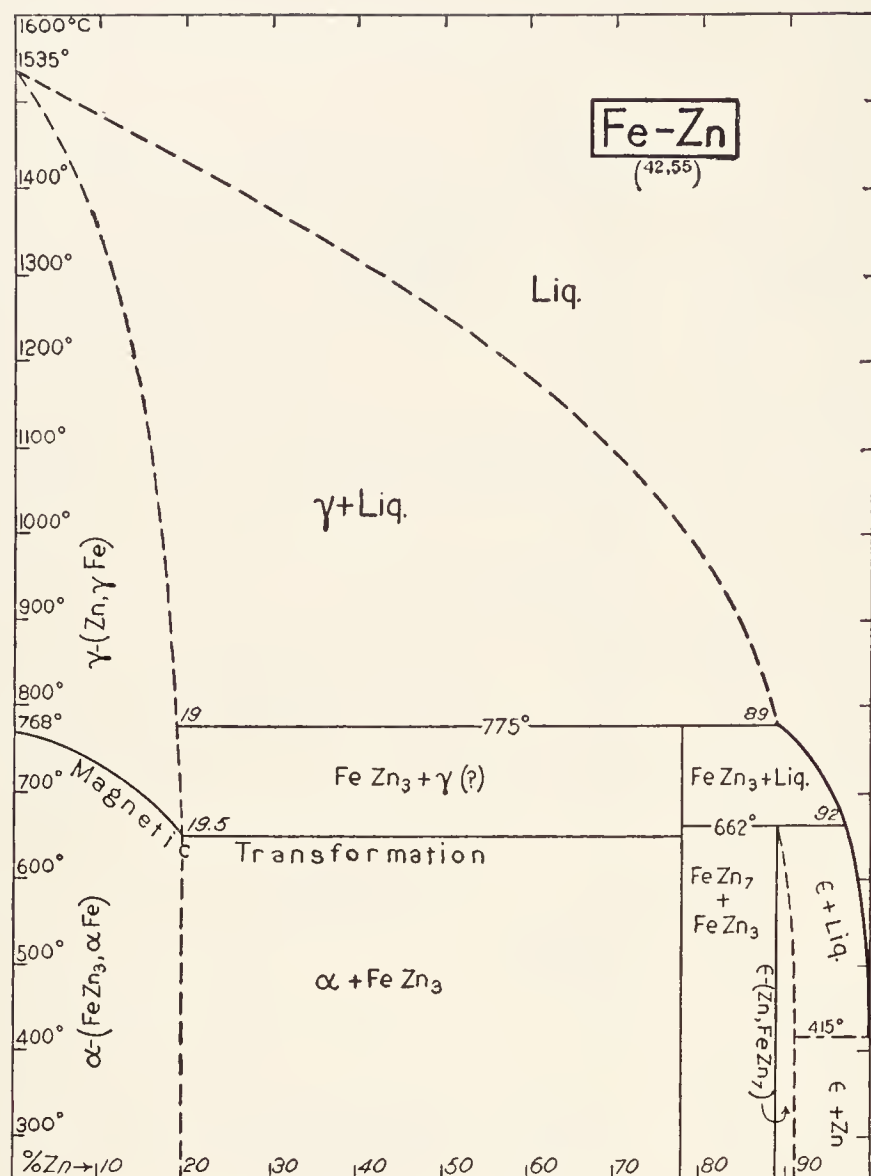




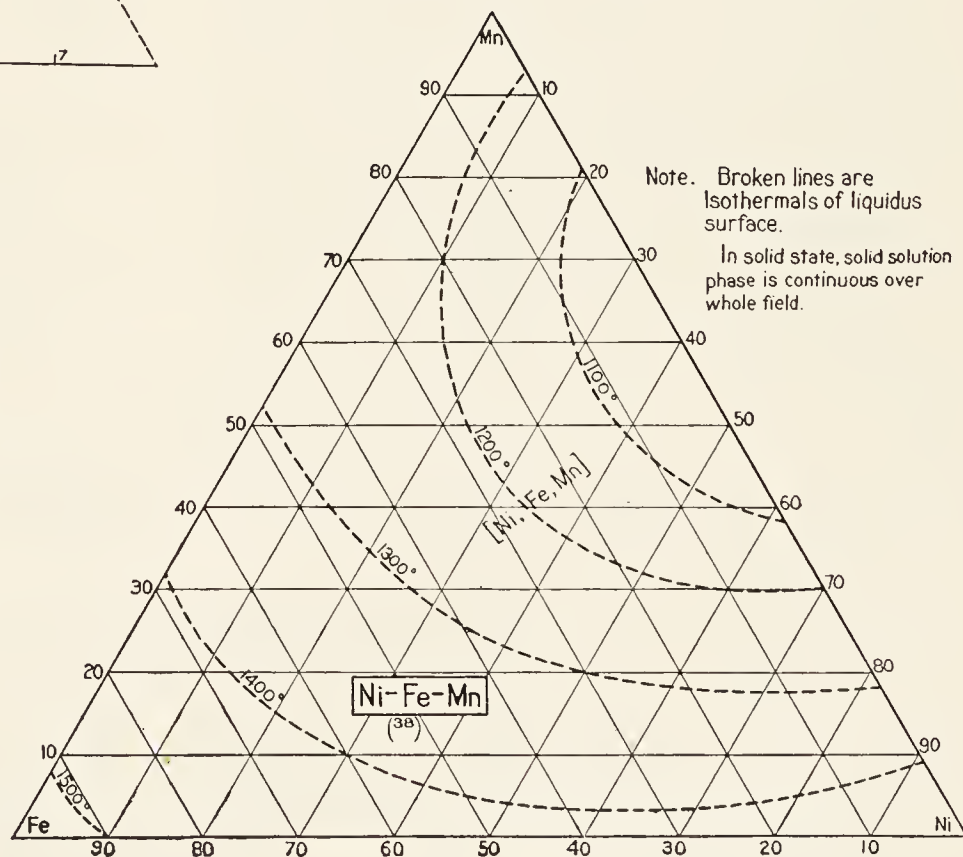
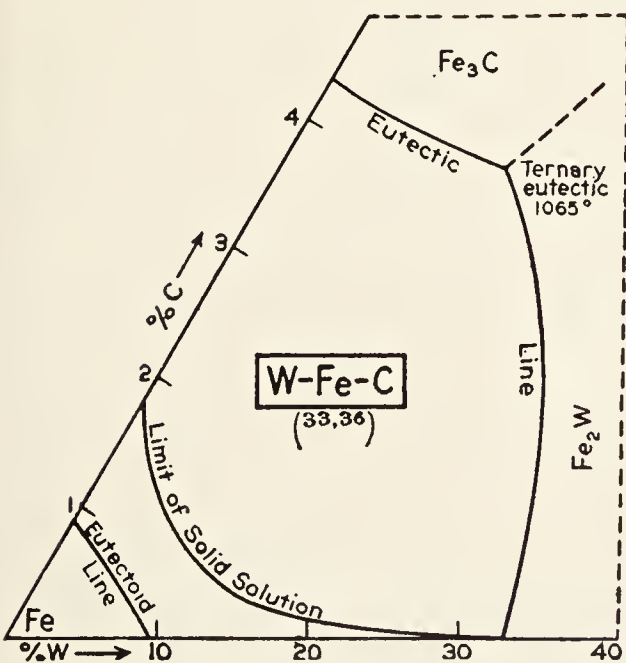
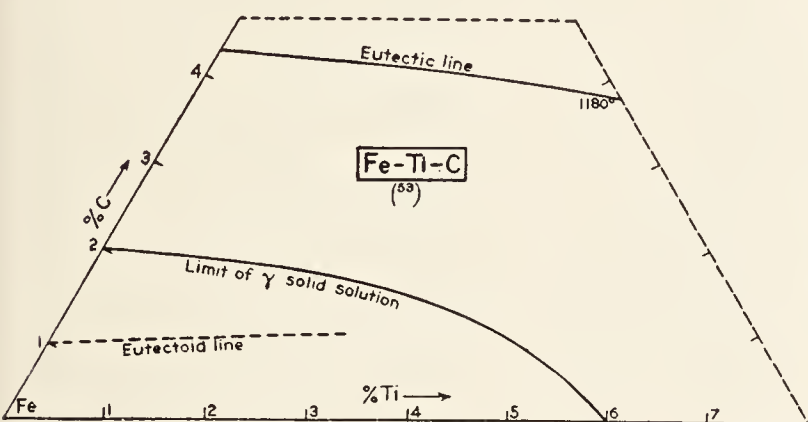
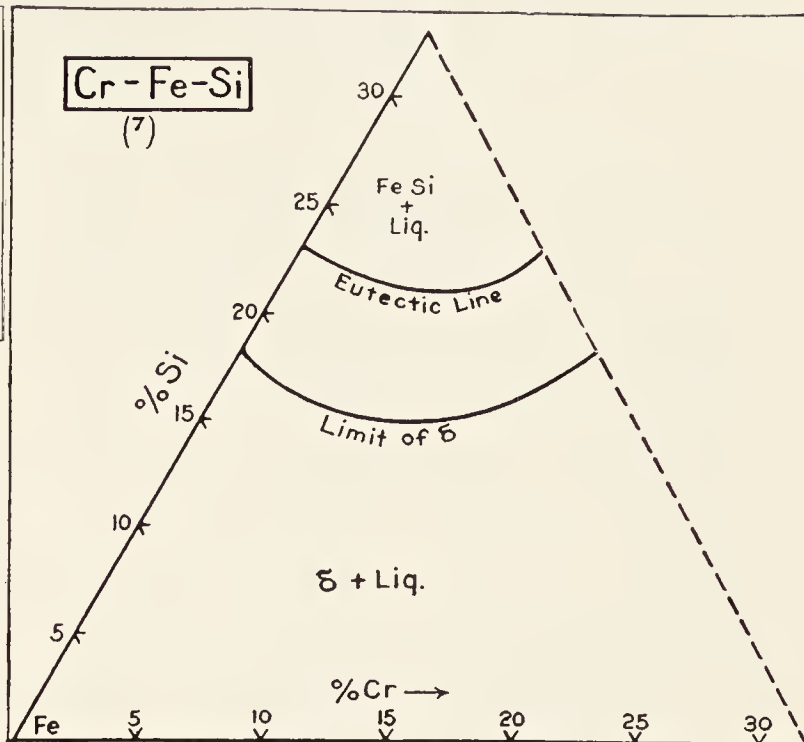
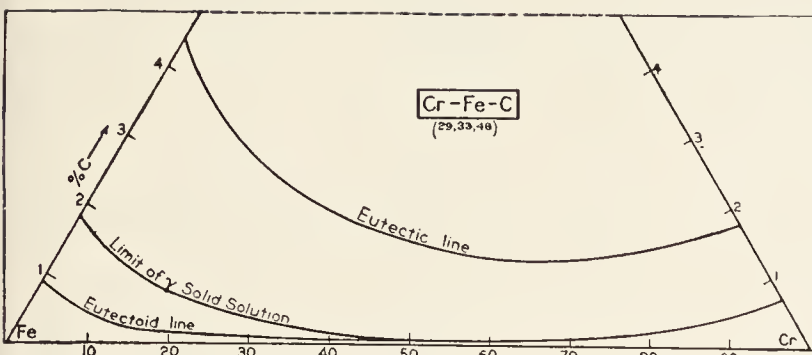












## DENSITY OF THE METALLIC ELEMENTS

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For values of density deduced from X-ray diffraction data, *v. vol. I, p. 340*

## PART I.—SOLID METALS

Metal	Condition	Temp., °C	$d_4^t$	Lit.	Coop. exp.
Ag*	Cast or cast and compressed	0	10.50	(1, 54, 55, 59, 65, 86, 93)	TKR
	Electrolytic.....	25	10.4914	(94)	
	Cast, compressed and heated to redness <i>in vacuo</i> ....	0	10.55	(93)	
	Drawn, annealed.....	20	10.4475	(44)	
	Hard drawn.....	20	10.4410	(44)	
	Distilled ( <i>in vacuo</i> ).....	20	10.4923	(43)	
	Cast disc heated to redness	0	10.4624	(93)	
	Same, struck.....	0	10.5023	(93)	
	Reheated red.....	0	10.4894	(93)	
	Struck again.....	0	10.5104	(93)	
	Reheated ( <i>in vacuo</i> ).....	0	10.4977	(93)	
	Fine powder by precipitation or decomposition of Ag <sub>2</sub> O and Ag <sub>2</sub> CO <sub>3</sub>		9.945 to	(46)	
			10.499		
Al	Cold rolled (99.97% Al)....	20	2.699	(17)	SLA
	Cast, pig (99.75% Al).....		2.684†	(18)	
	Cold rolled $\frac{1}{8}$ – $\frac{1}{4}$ in.....		2.703†	(18)	
	Cast (99.75% Al)**.....	20	2.703†	(18)	
As	Metallic.....	15	5.73	(49, 100)	CHD
	Yellow†.....	18	2.0	(21, 47)	
	Amorphous†.....	15	3.69	(49)	
	Black or gray.....	20	4.7	(21, 47)	
Au	Cast or cast and compressed.....	0	19.30	(83, 85, 88)	TKR
	Distilled, compressed by 10 <sup>4</sup> atm.....	20	19.2685	(43)	
	Drawn, annealed.....	20	19.2601	(44)	
	Hard drawn.....	20	19.2504	(44)	
	Precipitated from soln. by CH <sub>2</sub> O.....	20	19.3966	(5)	
	SO <sub>2</sub> .....	15	19.3587	(68)	
	Cold rolled sheet.....	0	19.2965	(86)	
	Same, annealed.....	0	19.2858	(86)	
		20	2.3	(73)	CHD
		25	3.5	(8)	CHD
Ba		20	1.84	(22)	CHD
Bi		20	9.80	(40)	OFH
C	Graphite.....	20	2.25 to 2.26	(4)	VHS
	Graphite after compression to 5000 atm.....	15	2.255	(50)	
	Graphite, fused in arc.....	16	2.232	(81)	
Ca		20	1.55	(7, 52, 60)	CHD
Cd	Cast.....	20	8.648	(20, 43)	CHMJ
	Cast, compressed.....	20	8.647	(54)	
	(Computed value).....	–273	9.65	(32)	
Ce		20	6.9	(62)	CHD
Co			8.9	(14, 45)	CHD
Cr			7.1	(79)	CHD
Cs		20	1.90	(31, 75)	CHD
Cu	Impurities negligible.....	20	8.94	(26, 43, 64)	DH
			±0.01		
Fe	Electrolytic: O <sub>2</sub> , 0.08 %; P, 0.007 %; melted <i>in vacuo</i> , rolled down 80 %; normalized 1000°C.....	20	7.90	(95)	DH
Ga		29.65	5.91	(74)	CHD
Ge		20	5.38	(15, 37)	CHD
Hf		20	11.4	(33)	Ed.
Hg		M.P.	14.43§	(16, 29, 56, 96)	Ed.
In		20	7.31	(77)	CHD

## PART I.—SOLID METALS.—(Continued)

Metal	Condition	Temp., °C	$d_4^t$	Lit.	Coop. exp.
Ir	Cast, hammered, slightly impure.....	0	22.4	(58, 63, 89)	TKR
K		20	0.86	(31, 75, 76)	CHD
La		15	6.16	(48, 62)	CHD
Li		20	0.53	(75)	CHD
Mg	Filings.....		1.7429	(54, 65)	AP
		20	1.7388		
		650	1.642	(19)	
Mn			7.2	(79)	CHD
Mo			10.2	(23)	CHD
Na		20	0.97	(28, 31, 75)	CHD
Nd		20	6.9	(62)	CHD
Ni			8.90±0.05	(13, 25, 39)	PDM
Os	Crystals		22.48	(42, 90)	TKR
Pb	Ordinary.....	20	11.3475	(20)	OFH
		19.94	11.337		
		19.94	11.289	(80)	
		16.34	11.3475		
		16.34	11.296	(20)	
Pd	From Australian uranium mineral.....	16.34	11.296		
	Cast.....		11.87	(55)	TKR
	Cast, hammered.....	0	12.1	(54, 63, 65, 73, 78)	
Pr		20	6.5	(62)	CHD
Pt	Cast and hammered or struck	0	21.46	(58, 63, 78, 89, 92)	TKR
	In mass.....	0	21.3351	(54, 65)	
	Filings.....		21.3705	(54, 65)	
	Annealed wire.....	20	21.4403	(44)	
	Hard drawn wire.....	20	21.4133	(44)	
		20	1.53	(75)	CHD
Rb			12.1	(88)	TKR
Rh	Cast.....		12.23	(30)	
	Hard drawn wire.....		12.5	(63, 103)	
	Cast and forged.....		12.2	(41, 91)	TKR
Ru	Cast, pulverized.....	0	7.7?	(62)	CHD
Sa		20	6.620	(43)	OFH
Sb		20	6.69	(43)	
	Pressed.....		6.71	(53)	
	Rhombohedral.....		2.4	(79, 97)	CHD
Si¶	Crystalline.....	20	7.30	(99)	OFH
Sn	White.....	20	5.85	(99)	
	Gray.....		2.6	(27)	CHD
Sr			16.6	(9)	CHD
Ta			11.7	(72)	CHD
Th			4.5	(38)	CHD
Ti		20	11.849	(104)	TKR
Tl			18.7	(101)	CHD
U		20	5.96	(37, 61)	CHD
V			19.3	(24)	CHD
W		20	7.139	(20)	CB
Zn	Different distillation fractions, variable isotopic proportion		7.1381 to 7.1420	(20, <i>v. also</i> 2, 12, 43, 102)	
		20	6.4	(98)	CHD
Zr					

\* For effect of annealing, *v. (56)*.

† Reduced *ad vacuum*.

‡ Probably not true allotropic forms.

§  $\frac{1}{V_{M.P.}} \frac{\Delta V}{\Delta t} = 0.000123$  per °C between –70° and the M. P.

|| No satisfactory determination on the homogeneous metal.

¶ Probably the only true form.

\*\* Corresponding to values given below for density of liquid metal.



## PART II.—LIQUID METALS

Metal	Temp., °C	$d_4^t$	Lit.	Coop. exp.
Ag	M. P.	9.46	(82)	TKR
	M. P.	9.51	(70, 84)	
	1000	9.653	(34)	
	1025	9.633	(34)	
	1050	9.613	(34)	
Al*	659	2.382	(18)	SLA
	1000	2.289	(18)	
Bi	271	10.24	(69)	OFH
Cd	8.02 — $\delta(t - 320)$ $\delta = 11 \times 10^{-4}$		(36)	CHMJ
	349	7.94	(3)	
	406	7.88	(3)	
	466	7.82	(3)	
	506	7.78	(3)	
	550	7.74	(3)	
	603	7.69	(3)	
Cs	28	1.84	(31)	CHD
Ga	29.8	6.09	(74)	CHD
Hg	<i>v. infra.</i>			
K	62.4	0.83	(31)	CHD
Mg	650	1.572	(19)	AP
	667	1.560 to 1.565	(19)	
Na	97.5	0.93	(28, 31)	CHD
	B. P.	0.74	(71)	
Pb	327	10.88	(66)	OFH
Rb	38.5	1.47	(31)	CHD
Sb	631	6.55	(66)	OFH
Sn	232	6.97	(66)	OFH
Zn	418	6.92	(67)	CB
	455	6.87	(67)	
	510	6.79	(67)	
	574	6.72	(67)	
	661	6.65	(67)	
	800	6.57	(67)	
	918	6.53	(67)	

\*99.75% Al. Corresponding value for  $d$  at 20°, 2.703.

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## Hg, DENSITY OF LIQUID MERCURY

V. STOTT AND PHILIP H. BIGG

The density of mercury at 0°C given in the table below is based on the following values: 13.59547 g/ml (Guye and Batuecas, *42*, 20: 308; 23); 13.5956 g/ml (Marek, *238*, 2: D; 83); 13.59545 g/ml (Thiesen and Scheel, *243*, 18: 138; 98).

Densities at other temperatures were calculated by means of

the formula:  $V_t = V_0[1 + 10^{-6}\{181.456t + 0.009205t^2 + 0.000006608t^3 + 0.00000067320t^4\}]$  (Sears, *67*, 26: 95; 13).

Chappuis' formula for the expansion of mercury between 0 and 100°C (Chappuis, *238*, 16: 17) would give the same values between these temperatures as those tabulated on p. 458.

## DENSITY AND SPECIFIC VOLUME IN MILLILITERS PER GRAM

$t, ^\circ\text{C}$	Density	Volume	$t, ^\circ\text{C}$	Density	Volume	$t, ^\circ\text{C}$	Density	Volume	$t, ^\circ\text{C}$	Density	Volume
(F. P.)											
-38.87	13.6919	0.073036	45	13.4851	0.074156	110	13.3278	0.075031	240	13.0176	0.076819
-30	13.6698	73154	50	13.4729	74223	120	13.3037	75167	250	12.9938	76960
-20	13.6450	73287				130	13.2797	75303			
-10	13.6202	73420	55	13.4608	0.074290	140	13.2558	75439	260	12.9700	0.077101
$\pm 0$	13.5955	73554	60	13.4486	74357	150	13.2319	75575	270	12.9462	77243
			65	13.4365	74424				280	12.9224	77385
5	13.5832	0.073620	70	13.4243	74492	160	13.2080	0.075712	290	12.8986	77528
10	13.5709	73687	75	13.4122	74559	170	13.1841	75849	300	12.8747	77672
15	13.5586	73754				180	13.1603	75986			
20	13.5463	73821	80	13.4001	0.074626	190	13.1365	76124	310	12.8508	0.077816
25	13.5340	73888	85	13.3880	74694	200	13.1127	76262	320	12.8268	77962
			90	13.3759	74761				330	12.8028	78108
30	13.5218	0.073955	95	13.3639	74829	210	13.0889	0.076400	340	12.7787	78255
35	13.5096	74022	100	13.3518	74896	220	13.0651	76540	350	12.7546	78403
40	13.4973	74089				230	13.0414	76679	357.1	12.7374	0.078509
									(B. P.)		

## LATENT HEAT OF PHASE CHANGES OF PURE METALS AND ALLOYS

M. L. GAYLER

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Conversion Factors: 1 kilojoule per g = 238.9 cal<sub>15</sub> g<sup>-1</sup> = 430.1 BTU<sub>60</sub> lb<sup>-1</sup> = 9.869 l-atm. g<sup>-1</sup> = 2.778 × 10<sup>-4</sup> kw hr g<sup>-1</sup>. For other factors, v. vol. 1, p. 16.

TABLE 1.—LATENT HEAT OF FUSION OF PURE METALS

Metal	$L_F$ , kilojoule per g-atom	Approx. error, %	M. P., $^\circ\text{C}$	Lit.
Ag	11.7	5	961	(23)
Al	9.82	3	657	(6, 8, 17)
Au	13.1	5	1064	(23)
Bi	8.93	5	270	(8, 23)
Cd	5.21	3	321	(8, 23)
Cs	2.09	2	28.5	(14)
Cu	11.1	3	1084	(6, 15, 23)
Fe*	11.5	5		(23)
Ga	5.56†	2	30	(1)
Hg	2.34	3	-38.7	(10, 13)
K	2.40	2	63.5	(14)
Mg	7.3	7	650	(8, 17)
Na	2.63	1	97.61	(7, 14)
Ni	17.9	1	1450	(22)
Pb	4.86	3	327	(8, 23)
Pd	16.1	10		(20)
Pt	22.0	10		(19)
Rb	2.18	1	38.7	(14)
Sb	19.8	3	630	(8, 23)
Sn	6.67	2	232	(6, 8, 23)
Tl	6.15‡			(16)
Zn	6.97	5	419	(8, 23)

\* Electrolytic Fe.

†  $L_F$  determined on super-cooled liquid at 13 and 14°C. The mean of these determinations is given and the author states that there is practically no difference in  $L_F$  between 0 and 30°C.

‡ Method not stated.

TABLE 2.—LATENT HEAT OF VAPORIZATION AT  $p$  MM Hg

Metal	$L_v$ , kilojoule per g-atom	Approx. error, %	$p$ , mm Hg	Lit.
Bi	141		$2 \times 10^{-3}$	(21)
Cd	84.7		$2 \times 10^{-3}$	(21)
Hg	53.3		$2 \times 10^{-3}$	(21)
Hg	57	4	760	(11)
Mg	172.7		$2 \times 10^{-3}$	(21)
Zn	99.8		$2 \times 10^{-3}$	(21)

TABLE 3.—LATENT HEAT OF TRANSFORMATION

Metal	Transformation	$L_T$ , kilojoule per g-atom	$t_T, ^\circ\text{C}$	Lit.
Ag	$\beta$ (octohedral) $\rightarrow \alpha$ .....	13.7*		(12)
As	$\alpha$ (rhombohedral) $\rightarrow \beta$ (amorphous gray)	4.18*		(12)
	$\gamma$ (amorphous brown) $\rightarrow \alpha$ (rhombohedral).....	14.0*		(12)
	Amorphous $\rightarrow$ crystalline.....	4.2*		(3)
Au	$\beta$ (dark) $\rightarrow \alpha$ (bright).....	13.4*		(12)
	$\gamma$ (metallic) $\rightarrow \alpha$ (bright).....	19.6*		(12)
Fe†	$\alpha \rightarrow \beta$ .....	1.53	725-785	(23)
	$\beta \rightarrow \gamma$ .....	1.56	919	(23)
	$\gamma \rightarrow \delta$ .....	0.45	1404	(23)
Mn	$\alpha \rightarrow \beta$ .....	5.55	1070-1130	(23)
Ni	$\alpha \rightarrow \beta$ .....	0.326	320-330	(23)
Sb	$\alpha$ (explosive) $\rightarrow$ ordinary.....	9.97*		(5)
Se	$\alpha$ (amorphous) $\rightarrow \beta$ (monoclinic).....	4.39*		(12)
	$\alpha$ (amorphous) $\rightarrow \gamma$ (crystalline).....	5.98*		(12)
	Amorphous $\rightarrow$ metallic.....	23.7*		(2)
Sn	White $\rightarrow$ gray.....	2.22	0	(4)
Te	Crystalline (sublimed) $\rightarrow$ amorphous...	101*		(2)

\* Difference between heats of oxidation.

† Electrolytic Fe.



TABLE 4.—LATENT HEAT OF FUSION OF ALLOYS

Alloy	$L_F$ , kilo-joule per g	Approx. error, %	M. P., °C	Lit.
Al <sub>2</sub> Cu.....	0.31	7	590	(17)
MgZn <sub>2</sub> .....	0.26	7	595	(17)
Monel metal (Ni, 68; Cu, 28; Fe, 2; Mn, 1.5).....	0.284	1		(22)
Pig iron, 4.34 % C.....	0.246			(18)
Gray cast iron.....	0.095	12	1350-1400	(9)
White cast iron.....	0.14	12	1050-1100	(9)

## LITERATURE

(For a key to the periodicals see end of volume)

- (1) Berthelot, *34*, **86**: 786; 78. (2) Berthelot, *B73*, **2**: 63; 97. (3) Berthelot and Engel, *14*, **21**: 284; 90. (4) Brönsted, *7*, **88**: 479; 14. (5) Cohen and Strengers, *7*, **52**: 129; 05. (6) Glaser, *192*, **1**: 103; 04. (7) Griffiths, *5*, **89**: 561; 14. (8) Awbery and Griffiths, *67*, **38**: 378; 26. (9) Gruner, *15*, **4**: 224; 73. *112*, **212**: 527; 74.  
 (10) Koref, *8*, **36**: 49; 11. (11) Kurbatov, *7*, **43**: 104; 03. (12) Petersen, *7*, **8**: 601; 91. (13) Pollitzer, *93*, **17**: 10; 11. (14) Rengade, *34*, **156**: 1897; 13. (15) Richards, *135*, **68**: 82; 93. (16) Robertson, *182*, **18**: 131; 02. (17) Roos, *93*, **94**: 329; 16. (18) Schmidt, *192*, **7**: 164; 10. (19) Violle, *34*, **85**: 543; 77.  
 (20) Violle, *34*, **87**: 981; 78. (21) Wehnelt and Musceleanu, *88*, **14**: 1032; 12. (22) White, *33*, **25**: 17; 21. (23) Wüst, Meuthen and Durrer, *414*, No. 204: 18.

## THERMAL EXPANSION INCLUDING VOLUME CHANGE ON FUSION, SOLIDIFICATION AND TEMPERING

J. S. CLARK

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## COEFFICIENTS OF EXPANSION OF PURE METALS

Definitions

 $l$  = length;  $V$  = volume;  $t$  = temperature, °C.

$$\alpha_{t_1}^{t_2} = \frac{l_2 - l_1}{l_1(t_2 - t_1)}; \quad A_{t_1}^{t_2} = \frac{V_2 - V_1}{V_1(t_2 - t_1)} \quad (\text{Mean coefficients})$$

$$\begin{aligned} \text{LINEAR} \quad \alpha_t &= \frac{dl}{ldt}; & \text{CUBICAL} \quad A_t &= \frac{dv}{Vdt} & (\text{True coefficients}) \\ l_t &= l_0(1 + \alpha t + \beta t^2 + \gamma t^3 + \delta t^4 + \dots); & V_t &= V_0(1 + At + Bt^2 + Ct^3 + \dots) \end{aligned}$$

TABLE 1.—THERMAL COEFFICIENT OF LINEAR EXPANSION OF METALS

Metal	Range, °C	$10^6\alpha^*$	$10^9\beta$	$10^{12}\gamma$ and $10^{15}\delta$	Probable error of $10^6\alpha$	Lit.
Ag.....	-200 to 300	18.7	5.9	$\begin{Bmatrix} -25.33\gamma \\ 53.3\delta \end{Bmatrix}$	$\begin{Bmatrix} \pm 0.5 \end{Bmatrix}$	(68, 88) (50, 74, 123) Comp.† Comp.†
	-200 to 0	16.1				(1)
	0 to 300	19.6				(84)
	-170 to 0	19.5	3.7	$-37\gamma$		
	0 to 900	20.5				
Al.....	-200 to 0	22.65	16.75	$-36.67\gamma$	$\pm 0.03, 0^\circ$	(1, 68) Comp.† Comp.†
	-200	11.55				
	-100	18.2				
	0 to 600	22.65	9.5		$\begin{Bmatrix} \pm 0.03, 0^\circ \\ \pm 0.8, 600^\circ \end{Bmatrix}$	(37, 50, 80, 84, 91, 125, 129)
99.95	0 to 600	22.58	9.89			(70)
99.74	0 to 600	21.90	12.0		$\pm 0.2$	(129)
99.15	20 to 200	25.9				(70)
	20 to 400	27.2				(70)
	20 to 600	28.7				(70)
	0 to 100	24.32				(17)
Hard drawn.....	0 to 100	24.54				(17)
As.....	10 to 90	3.86	21.6	Sublimed; mixed crystals		(50)
Au.....	-100 to 500	14.13	2.768	$-0.911\gamma$	$\pm 0.1$	(39, 40, 50, 56, 98)
	-100 to 0	13.84				Comp.†
	0 to 100	14.40				Comp.†
	100 to 300	15.1				Comp.†
	300 to 500	15.9				Comp.†

TABLE 1.—THERMAL COEFFICIENT OF LINEAR EXPANSION OF METALS.—(Continued)

Metal	Range, °C	$10^6\alpha^*$	$10^3\beta$	$10^{12}\gamma$ and $10^{15}\delta$	Probable error of $10^6\alpha$	Lit.
Bi.....	-183 to 15	12.98				(56)
	-183 to 15	12.24				(39)
	19 to 101	13.45				(56)
	16 to 35	13.43				(139)
	0 to 270	14.6				(138)
	8 to 180	15.7				(91)
	10 to 90	15.37	10.45			(50)
	20	13.96				(16)
	20 to 240	16.2†			±0.1	(116)
⊥	10 to 90	10.84	15.55			(50)
⊥	20	10.36				(16)
⊥	20 to 240	12.0†			±0.1	(116)
Ca.....	0 to 21	25	Calculated from cubical coefficients			(15)
C.....		Graphite, v. Table 11				
Cd.....	-160	59.0			v. also Fig. 1	(57)
	60	52.5				(57)
⊥	-160	12.2				(57)
⊥	60	21.8				(57)
Mean (calc.).....	-160	27.8	{ Mean (calc.) $\frac{\alpha_{  } + 2\alpha_{\perp}}{3}$			(57)
Mean (calc.).....	60	32.0				(57)
Mean (obs.).....	-170 to 200	29.1	17.9			(39, 50)
Mean (obs.).....	0 to 315	38				(138)
Co.....	6 to 120	12.08	6.4			(136)
	25 to 350	18.1				(108)
Cr.....	0 to 500	8.11	3.23			(36)
	- 78 to 0	7.31				(36)
98.3 (+Al, Fe, etc.)	0	6.8				(24)
	200	9.0				(24)
	300	9.8				(24)
	600	12.3				(24)
	900	14.7				(24)
Cs.....	0 to 26	97	Calculated from cubical coefficients			(64)
Cu.....	-100 to 400	16.2	9.5	$\begin{Bmatrix} -20_{\gamma} \\ 23_{\delta} \end{Bmatrix}$	$\pm 0.2, 0^{\circ}$ $\pm 0.4, 400^{\circ}$	(50, 68) (37, 69)
	-250 to -193	3.9				(88)
	-193 to -183	6.8			also Fig. 2	(88)
	-187 to 19	12.3				(88)
	0 to 1000	20.0				(84)
Cu, 99.6; Ni, 0.35..	25 to 300	16.7	3.3	Idem. for Cu, 99.4; As, 0.54		(69)
Fe.....	0 to 700	11.45	7.0	$\begin{Bmatrix} -3.63_{\gamma} \\ 1.2_{\delta} \end{Bmatrix}$	±0.3	(41, 63, 74, 130)
	0 to 100	12.1				Comp.†
	0 to 300	13.2				Comp.†
	0 to 500	14.2				Comp.†
	0 to 700	15.0				Comp.†
	-190 to 20	9.18				(39, 68)
	>890§	ca. 23				(63)
Ga.....	0 to 30	18.3	Calculated from cubical coefficients			(114)
In.....	10 to 90	24.75	211.9			(50)
Ir.....	-150 to 800	6.41	3.197	$\begin{Bmatrix} -4.333_{\gamma} \\ 2.629_{\delta} \end{Bmatrix}$	$\pm 0.2, -150^{\circ}$ $\pm 0.1, 600^{\circ}$	(56, 137) (5, 50, 76)
	-150 to -50	5.64				Comp.†
	- 50 to 50	6.40				Comp.†
	50 to 150	6.92				Comp.†
	150 to 300	7.3				Comp.†
	300 to 800	7.8				Comp.†
	1000	9.02				(76)
	1250	9.60				(76)
	1500	10.18				(76)
	1750	10.76				(76)



TABLE 1.—THERMAL COEFFICIENT OF LINEAR EXPANSION OF METALS.—(Continued)

Metal	Range, °C	$10^6\alpha^*$	$10^9\beta$	$10^{12}\gamma$ and $10^{15}\delta$	Probable error of $10^6\alpha$	Lit.
K.....	0 to 50 0 to 56 0 to 58 0 to 58	83.3 79.7 70.4 72.0	69.7 51.7	{ Calculated from cubical coefficients }		(65) (65) (6) (64)
Li.....	0 to 178	51.2	31	Calculated from cubical coefficients		(6)
Mg.....	-150 to 500  -100 to 0 0 to 100 0 to 300 0 to 500	25.0  23.4 26.4 28.5 29.6	15.0	-11.6 $\gamma$	{ $\pm 1.0$ , $-100^\circ$ $\pm 0.5$ from 0 to $500^\circ$	(50, 72) (56, 123) Comp.† Comp.† Comp.† Comp.†
Mn.....	-190 to 20 0 to 300	23.03 21.61	37.2 12.1			(36) (36)
Mo.....	-190 to 20 0 to 400	5.1 5.1	5.7 1.3			(36, 120) (36, 120)
W, 1.85 % (v. also Table 34)	25 to 100	5.2				(71)
	25 to 250	5.4				(71)
	25 to 500	5.6				(71)
	500 to 600	6.2				(71)
	600 to 700	6.4				(71)
	500 to 750	6.3				(71)
	25 to 100	3.7 to 5.0				(71)
	25 to 250	4.4 to 5.1				(71)
	25 to 500	4.7 to 5.7				(71)
Na.....	-191 to 17 0 to 50  0 to 90	62.2 72.1 69 64	87			(35) (65) (13, 14) (6, 55, 64, 65)
Ni.....	-200 to 350  -100 to 0 0 to 100 100 to 200 200 to 300 350 to 550 500 to 1000 0 to 1000	12.54  11.6 13.3 14.7 15.9 ca. 19.0 13.46 18.2	8.75     Critical region 3.31	{ -7.5 $\gamma$ 6.25 $\delta$	{ 1.0, $-200^\circ$ $\pm 0.1$ , $0^\circ$ $\pm 0.4$ , $300^\circ$	(58, 63, 136) (30, 36, 74) (66, 112) Comp.† Comp.† Comp.† Comp.† (66) (74) (84)
Commercial, 94 to 99 %	25 to 100	12.9 to 13.5				(129)
	25 to 300	13.8 to 14.6				(129)
	25 to 600	14.9 to 15.7				(129)
Os.....	10 to 90	5.70	10.9			(50)
Pb.....	-200 to 150  -200 -100 100 0 to 320	28.3  19.5 25.2 30.6 33	12	{ -13.3 $\gamma$ 75 $\delta$	$\pm 1.0$	(39, 40, 50, 56, 88, 113) Comp.† Comp.† Comp.† (138)
Pd.....	-200 to 100  -200 to -100 -100 to 0 0 to 100 0 to 1000	11.60  9.75 11.10 11.93 11.67	4.15    2.19	-8.67 $\gamma$	{ $\pm 0.3$ , $-100^\circ$ $\pm 0.1$ , $0^\circ$	(50, 68, 74, 121) Comp.† Comp.† Comp.† (74)
Pt.....	-150 to 600  -150 to -50	8.786  7.97	3.118	{ -5.2 $\gamma$ 4.095 $\delta$	{ $\pm 0.1$ , $-100^\circ$ $\pm 0.05$ , $0^\circ$ $\pm 0.1$ from 100 to $600^\circ$	(5, 50, 68, 74, 103, 121, 124, 137) Comp.†

TABLE 1.—THERMAL COEFFICIENT OF LINEAR EXPANSION OF METALS.—(Continued)

Metal	Range, °C	$10^6\alpha^*$	$10^3\beta$	$10^{12}\gamma$ and $10^{15}\delta$	Probable error of $10^6\alpha$	Lit.
Pt.—(Continued).....	— 50 to 50	8.76				Comp.†
	50 to 150	9.26				Comp.†
	150 to 300	9.6				Comp.†
	300 to 600	10.0				Comp.†
	800	10.98				(74)
	1000	11.51				(15)
	0 to 1670	9.75				(126)
Rb.....	0 to 38	90	Calculated from cubical coefficients			(64)
Rh.....	—180 to 100	8.19	4.217	$\begin{cases} -7.0\gamma \\ 51.67\delta \end{cases}$	$\begin{cases} \pm 0.1, < -100^\circ \\ \pm 0.05, > -100^\circ \end{cases}$	(50, 137)
	—180 to —100	6.5				(50, 137)
	—100 to 0	7.65				Comp.†
	0 to 100	8.59				Comp.†
Ru.....	10 to 90	8.51	14.05			(50)
Sb.....	—190 to 17	10.22				(56, 137)
	17 to 100	10.88				(56, 137)
	9 to 72	11.77				(91)
	10 to 90	11.29	2.9			(50)
	10 to 90	17.3	—4.7			(50)
	20	15.56				(16)
⊥	—180 to 20	8.2				(39)
⊥	10 to 90	8.28	6.7			(50)
⊥	20	7.96				(16)
⊥	100 to 300	10.0				(12)
Si.....	—191 to 18	2.5	7.7			(137)
	0 to 100	6.95	8.5	<i>v. also</i> Table 37		(50)
Sn, 99.9%.....	—163 to 18	16				(29)
White..... {	10 to 90	20.9	17.5			(50)
	20 to 232	23 to 24				(29, 138)
Gray.....	—163 to 18	5.3				(29)
Single crystals {	20	30.5				(16)
	⊥ 20	15.45				(16)
Ta.....	—78 to 0	5.9				(36)
	0 to 400	6.46	0.9			(36)
Tl.....	10 to 90	25.65	57.0			(50)
	0 to 294	33				(102)
W.....	—190 to 0	3.8				(36)
	0 to 400	4.46	0.73			(36)
	17 to 577	4.5				(53)
99.99..... {	577 to 1377	5.71				(53)
	1377 to 2227	7.27				(53)
W, 99; Th, 1.....	20 to 675	4.56				(38)
	27	4.44				(141)
	1027	5.19				(141)
	2027	7.26				(141)
	—150 to 502	4.28	0.58		¶	(71.2)
	30 to 630	4.67**				(52)
	630 to 830	4.00**				(52)
	830 to 2430	4.87**	9.45	$\begin{cases} l_t = l_1[1 + \alpha(t - t_1) + \beta \\ (t - t_1)^2] \end{cases}$		(52)
Zn.....	—170 to 60	29.5	21.6	—40 $\gamma$		(39, 40, 50, 57)
	0 to 300	35.4	10			(125)
99.99.....	20 to 250	39.5	(Cast)			(70)
	—160 to 60	57 to 64			<i>v. also</i> Fig. 1	(16, 57)
⊥	—160	6.6				(57)
⊥	20	12.6				(16)
⊥	60	15.6				(57)
	—220 to 60	13.5	2.37			(56, 57, 88)

\* If only  $\alpha$  is given and only one temperature,  $\alpha = \alpha_t$ ; if only  $\alpha$  and a temperature range,  $\alpha = \alpha_{t_1}^{t_2}$ .† Computed, using the above values of  $\alpha$ ,  $\beta$ ,  $\gamma$ ,  $\delta$ .

‡ Practically constant between 20 and 240°C.

¶ Probable error of  $l_t = \pm 8 \times 10^{-6}$  %.

\*\* Aged lamp filaments.

§ Critical temperature.



TABLE 2.—THERMAL COEFFICIENT OF CUBICAL EXPANSION OF METALS (SOLID)

$$V_t = V_0 (1 + At + Bt^2)$$

Metal	Range	10 <sup>6</sup> A	10 <sup>6</sup> B	Lit.
Ca.....	0 to 21°C	75		(15)
Cs.....	0 to 26°C	291		(64)
Ga.....	0 to 30°C	55		(114)
Hg; v. p. 456				
K.....	0 to 50°C	239	209	(65)
	0 to 56°C	211.2	155	(6)
	0 to 58°C	250		(64)
Li.....	0 to 178°C	153.5	92	(6)
Na.....	-191 to 16°C	186.5		(35)
	0 to 78°C	181.6	280	(6)
	0 to 95°C	204	242	(65)
	0 to 80°C	216		(64)
Rb.....	25 to 100°C	226		(55)
	0 to 38°C	270		(64)
	1.6 to 17.5°C	268.6		(34)

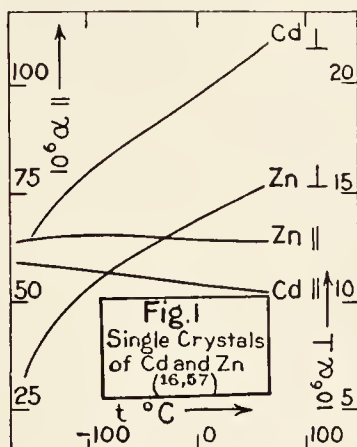


TABLE 3.—SPECIFIC GRAVITY AND THERMAL COEFFICIENT OF CUBICAL EXPANSION OF LIQUID METALS

$$V_t = V_0 [1 + A(t - \theta) + B(t - \theta)^2 + C(t - \theta)^3 + \dots], \text{ } ^\circ\text{C}$$

Metal	Approx. M. P., $^\circ\text{C}$	$d_4^\theta$	10 <sup>6</sup> A	10 <sup>6</sup> B	Range, $^\circ\text{C}$	Lit.
Ag.....	960	9.51				(117)
$d_4^{18.5} = 10.33$ .....		9.32	111		960 to 1100	(118)
Al 99.8.....	658	2.382	114		650 to 1100	(43)
99.4.....	658	2.384			650 to 1100	(43)
98.3.....	658	2.405			650 to 1100	(43)
99.4.....	658	2.41	142		658 to 1000	(105)
98.7 to 99.2.....	658	2.399	125		658 to 882	(9)
Au.....	1063	(17.1)				(109)
Bi.....	275	10.07	124		269 to 472	(73)
		10.00	120		270 to 300	(138)
		10.055				(117)
		10.03	121		360 to 630	(11)
Cd, electrolytic.....	320	7.99	170		318 to 351	(138)
		8.02	137		320 to 544	(73)
Cu 99.9.....	1083	8.40	{ 62   -560 10 <sup>12</sup> C = 5600 }		1083 to 1295	(105)
		8.22				(117)
		7.99			1083 to 1200	(9)
Cs.....	26	1.836	379		27 to 40	(42)
			395		27 to 100	(42)
			341		28 to 50	(64)
			348		50 to 123	(64)
Fe { C, 0.1%.....	1530	7.0				(117)
						(4)
						(119)
C, 0.2-0.25%.....	1540	6.92 $\pm$ 0.07				
C, 3.3; Si, 2.76%*	1150	6.97				
Hg; v. p. 457						
K.....	62	0.8298	299		62 to 100	(65)
			280		70 to 100	(64)
			285		100 to 150	(64)
			268	210	78 to 235	(6)

TABLE 3.—SPECIFIC GRAVITY AND THERMAL COEFFICIENT OF CUBICAL EXPANSION OF LIQUID METALS.—(Continued)

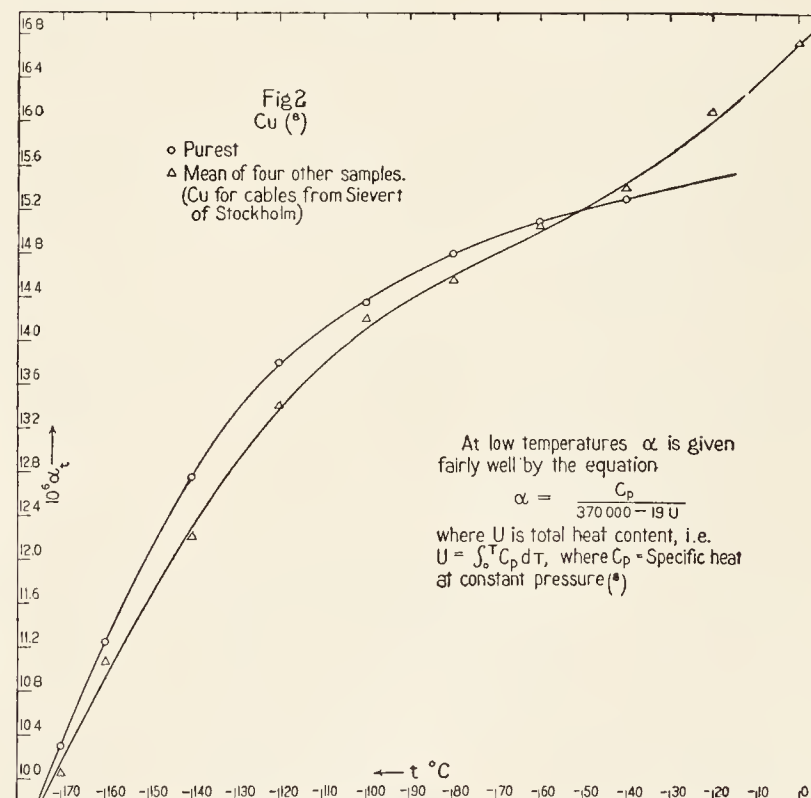
$$V_t = V_0 [1 + A(t - \theta) + B(t - \theta)^2 + C(t - \theta)^3 + \dots], \text{ } ^\circ\text{C}$$

Metal	Approx. M. P., $^\circ\text{C}$	$d_4^\theta$	10 <sup>6</sup> A	10 <sup>6</sup> B	Range, $^\circ\text{C}$	Lit.
Li.....	185		174	106	185 to 235	(6)
Mg.....	650	1.572	(380)		650 to 800	(44)
		(1.545 at 730°)				(118)
Na.....	98	0.9287	278		98 to 170	(65)
			275		100 to 180	(64)
			260	286	100 to 235	(6)
			390†		98 to 750	(110, 111)
Pb.....	327	10.65	129		325 to 357	(138)
		10.69	120		327 to 825	(33)
		10.71	130		327 to 522	(73)
Pb, electrolytic.....		(10.47 at 500 $\pm$ 5°)				(4)
Pd.....	1550	(10.8)				(109)
Pt.....	1755	(18.9)				(109)
Rb.....	38	1.472	339		40 to 140	(64)
Sb, 99.9%.....	630	6.55	41	120	631 to 1074	(105)
		6.49	104		700 to 1040	(10)
Sn, electrolytic 99.9%.	232	6.97	105		400 to 700	(11)
		7.01	106		232 to 396	(73)
		6.98	{ 126   -171 10 <sup>12</sup> C = 146 }		232 to 988	(102)
		6.98	100		232 to 1600	(33)
		6.99	114			(138)
		7.025				(117)
		(6.95 at 320 $\pm$ 5°)				(4)
Tl.....	300	11.032	150		302 to 351	(102)
Zn, electrolytic 99.9%.	419	6.59	147		419 to 543	(73)
		6.92	217	-198	419 to 918	(105)

The values in parentheses in the  $d_4^\theta$  column are very old single determinations and are probably only approximate.

\* Gray pig iron.

† Based on Ramsay's value of density at B. P.



## COEFFICIENTS OF EXPANSION OF SOLID ALLOYS

First consult Table 4, which is a complete index of the section. The arrangement is alphabetical under the chemical symbol of the major constituent, as explained above, p. 360.

For definitions and symbols, v. p. 392.

TABLE 4.—GENERAL TABLE

Ag-Au; v. Table 38.

Ag-Cu					
% composition	Ind. No.	Range, °C	10 <sup>6</sup> $\alpha$	10 <sup>9</sup> $\beta$ and 10 <sup>12</sup> $\gamma$	Lit.
Ag, 77; Cu, 23.....	1253	0 to 800	18.0		(84)

Ag-Hg-Zn; v. Table 32.

Ag-Pt; v. Table 38.

## Al-Cr-Ni-Cu-Mn

Al, 95.5; Ni, 1.5; Cr, 1.5; Cu, 1.0; Mn, 0.5	1452	14 to 302	21.05	14.73 $\beta$	(70)
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Al-Cu; v. also Table 5 and Fig. 3

Al, 95; Cu, 5 to Al, 87; Cu, 13		20 to 100	22.2-24.6		(70)
		20 to 200	23.6-26.8		(70)
		20 to 300	26.4-29.2		(70)
Al, 82; Cu, 18.....		15 to 100	21.9		(85)
Al, 70; Cu, 30.....		15 to 100	20.0		(85)
Al, 67; Cu, 33.....		15 to 100	16.2		(85)
Al, 50-0; Cu, 50-100..		15 to 100	15.7-16.5		(85)

Al-Cu-Mg-Si; v. also Table 6

Al, 94.4-94.8; Cu, 3.66-3.74; Mg, 0.36-1.08; (Mn, Fe, Si)	508	20 to 100	21.9-23.8		(70)
		20 to 200	22.9-26.0		(70)
		20 to 300	24.7-26.9		(70)
		20 to 400	25.7-27.3		(70)
		20 to 500	25.4-27.6		(70)

## Al-Mg

Al, 96; Mg, 3 (Fe, Sb)	824	0 to 13	22.0		(61)
Al, 85.9; Mg, 17.7 (Si, Fe, Cu).....	824	12 to 39	23.8		(132)

Al-Mn-X; v. Table 7.

Al-Cu-Si; Al-Mn; Al-Mn-Cu; v. Table 7.

Al-Si; v. also Table 8

Al, 95; Si, 5 to Al, 87; Si, 13		20 to 100	19.2-22.2		(70)
		20 to 200	20.2-23.2		(70)
		20 to 300	22.2-24.8		(70)

Al-Si-Cu; Al-Si-Mn-Cu; v. Table 7.

Al-Zn; v. also Tables 9 and 10, and Fig. 4

Al, 86; Zn, 14 to Al, 5; Zn, 95; v.		20 to 100	24.3-33.3		(70)
		20 to 200	27.3-37.2		(70)
		20 to 300	28.3-40.7		(70)
Al, 100; Zn, 0 to Al, 0, Zn, 100		25 to 250	27.1-32.6		(128)
		20 to 250	27.7-38.2		(125)

Al-Cu-Fe-Mn-Si; v. Table 7.

Au-Ag; v. Table 38.

Au-Cu; v. also Table 38

Au, 91.66; Cu, 8.33...		0 to 85	14.57	3.19 $\beta$	(5)
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Bi-Pb; v. Table 38.

Bi-Sn; v. Table 38.

C (Graphite); v. Table 11.

Cd-Pb; v. Table 38.

Co-Cr; v. also Table 12

Co, 55-80; Cr, 20-40 + C, W.....	1344	20 to 600	13.6-16.5		(129)
Co, 55; Cr, 35; W, 10	1345	-94 to 19	10.2		(129)

Co-Cr-W-C (Stellite); v. Table 12.

Cr-Fe-C-Si; Cr-Fe-Si-C; v. Table 13.

Cu-Al; v. also Al-Cu and Fig. 3

Cu, 92.2; Al, 7.3; Zn, 0.4 (Rh).....	103	20 to 300	15.57	8.05 $\beta$	(69)
Same, D <sub>c</sub> .....		20 to 300	15.79	6.45 $\beta$	(69)

## Cu-Ni

Cu, 60; Ni, 40.....	405	-191 to 16	12.22		(68)
Cu, 60; Ni, 40.....	405	0 to 500	14.81	4.02 $\beta$	(74)

Cu-Sb; v. also Fig. 3

Cu, 100; Sb, 0.....		25 to 100	16.3		(85)
Cu, 95; Sb, 5.....		25 to 100	19.2		(85)
Cu, 90; Sb, 10.....		25 to 100	20.2		(85)
Cu, 85; Sb, 15.....		25 to 100	20.0		(85)
Cu, 80; Sb, 20.....		25 to 100	19.2		(85)
Cu, 57; Sb, 43.....		25 to 100	14.5		(85)
Cu, 33; Sb, 67.....		25 to 100	11.5		(85)
Cu, 10; Sb, 90.....		25 to 100	9.1		(85)
Cu, 0; Sb, 100.....		25 to 100	10.0		(85)
Cu, 100; Sb, 0.....		100 to 300	16.4		(12)

TABLE 4.—GENERAL TABLE.—(Continued)

Cu-Sb.—(Continued)

% composition	Ind. No.	Range, °C	10 <sup>6</sup> $\alpha$	10 <sup>9</sup> $\beta$ and 10 <sup>12</sup> $\gamma$	Lit.
Cu, 96; Sb, 4.....		100 to 300	17.9		(12)
Cu, 93; Sb, 7.....		100 to 300	19.1		(12)
Cu, 85; Sb, 15.....		100 to 300	20.0-20.5		(12)
Cu, 68; Sb, 32.....		100 to 300	23.3-23.8		(12)
Cu, 61.4; Sb, 38.6....		100 to 300	23.4-24.2		(12)
Cu, 60; Sb, 40.....		100 to 300	23.3-24.2		(12)
Cu, 55; Sb, 45.....		100 to 300	23.0-23.8		(12)
Cu, 50; Sb, 50.....		100 to 300	21.6-22.5		(12)
Cu, 45; Sb, 55.....		100 to 300	20.0-21.6		(12)
Cu, 28; Sb, 72.....		100 to 300	17.4		(12)
Cu, 3; Sb, 97.....		100 to 300	11.2		(12)
Cu, 1; Sb, 99.....		100 to 300	9.3		(12)
Cu, 0; Sb, 100 cast....		100 to 300	10.0		(12)
Same, agglomerate....		100 to 300	8.3		(12)

Cu-Si; v. also Table 15.

Cu-Si, 3.....	452	15 to 900	17.88		(2)
Cu-Si, 6.....		15 to 900	17.83		(2)
Cu-Si, 10.....		15 to 700	16.08		(2)
Cu-Si, 55.....		15 to 1000	3.87		(2)

Cu-Si-Fe; v. Table 15.

## Cu-Sn

Cu, 95.4; Sn, 4.25; P, 0.37.....	1082	20 to 300	16.81	3.59 $\beta$	(69)
Cu, 94.9; Sn, 4.88; P, 0.12.....	345	20 to 300	16.63	3.67 $\beta$	(69)
Cu, 92.0; Sn, 7.67; P, 0.11.....	664	20 to 300	16.82	4.25 $\beta$	(69)
Cu, 89.7; Sn, 10.14 (Re).....	664	20 to 300	17.13	3.70 $\beta$	(69)

Cu-Zn; v. also Tables 16, 17 and 38 and Fig. 6

Cu, 97-65; Zn, 3-35...		25 to 300	17.7-20.8		(69)
Cu, 60; Zn, 40.....	918	25 to 300	20.7-21.2		(69)
Cu, 88-62; Zn, 35-10; Pb, 1.65-2.57.....	777	25 to 300	18.3-20.4		(69)
Cu, 56.39; Zn, 40.59; Sn, 1.52; Fe, 0.96; Mn, 0.09; Pb, 0.09 (Rh).....	842, 845	25 to 300	21.5-22.7		(69)

Cu-Zn-Pb; v. Table 16.

Cu-Zn-Sn; v. Table 17.

Fe-C; v. also Tables 18, 19, 20, 23, 28 and 31 and Fig. 7

Fe with C, 3-4.....	661	-191 to 16	8.5		(68)
Fe with C, 3.12; Si, 3.37.....	661	0 to 700	8.3	8.3 $\beta$	(83)
Fe with C, 3.08; Si, 1.68.....	661	25 to 100	8.4		(130)
		100 to 200	11.7		(130)
		200 to 300	14.2		(130)
		300 to 400	15.6		(130)
		400 to 500	14.3		(130)
Fe with C, 3.04; Si, 1.65; P, 1.3; Mn, 0.2	661	15 to 1000	13.34		(2)
Same, T <sub>p</sub> , 1000°; Q <sub>w</sub> , 15°.....		15 to 1000	14.02		(2)
Fe with <1.4 C.....		-200	5.8-8.4		(23)
Fe with <3.8 C		20 to 1000	13.1-19.6		(21)
		25 to 600	14.3-14.6		(22)
		> Crit. temp.	ca. 23		(22)
Fe with C <1.5; Mn, 0.27-0.67.....		15 to 75	10.8-12.1		(20)

## Fe-Co-Cr-C

Fe, 55.3; Co, 22.5; Cr, 21.2; C, 0.7.	588	20 to 100	15.6		(129)
		100 to 200	16.7		(129)
		200 to 300	17.6		(129)
		300 to 400	17.8		(129)
		400 to 500	17.6		(129)
		500 to 600	17.0		(129)

Fe-Cr-C; v. also Tables 13, 21, 22, 28, 29 and 31

Fe-Cr, 13, etc.....		20 to 600	11.2-12.1		(22)
Fe; Cr, 3.1-7.4; Si, 0.5-2.4		15 to 900	12.6-14.9		(2)

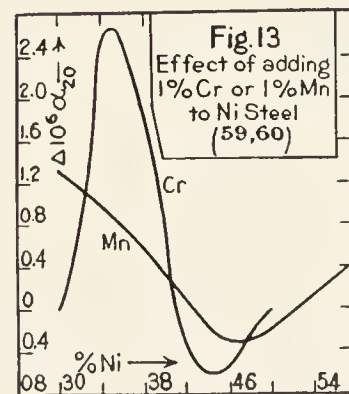
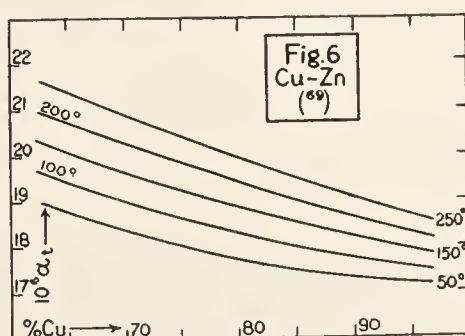
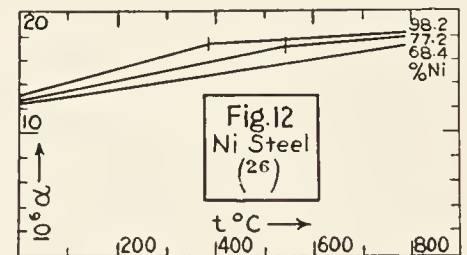
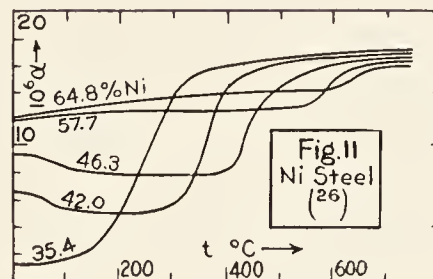
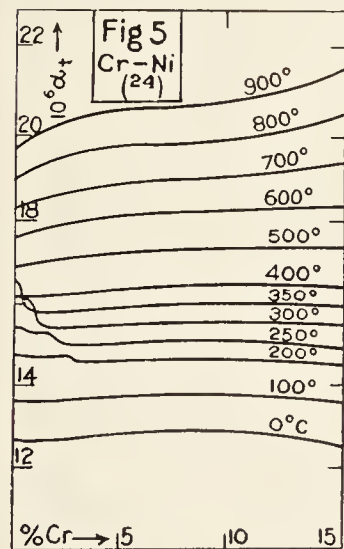
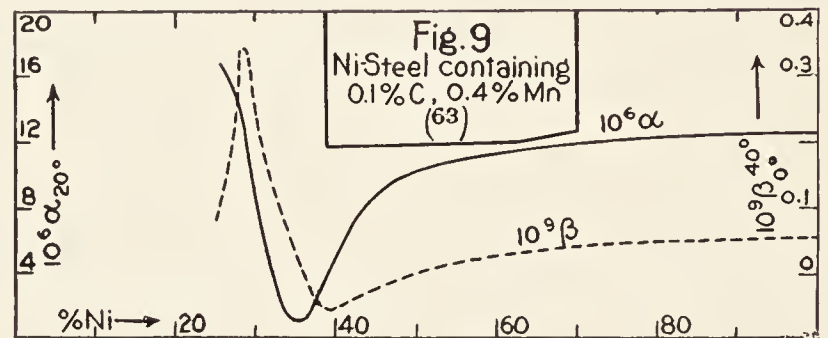
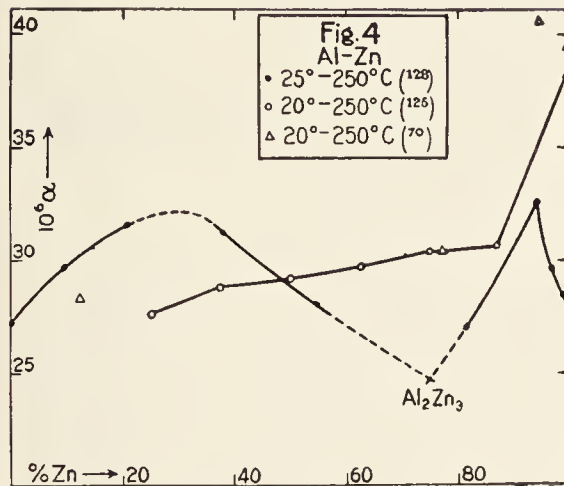
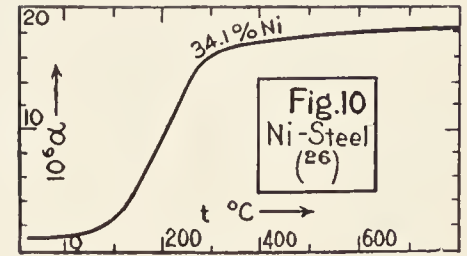
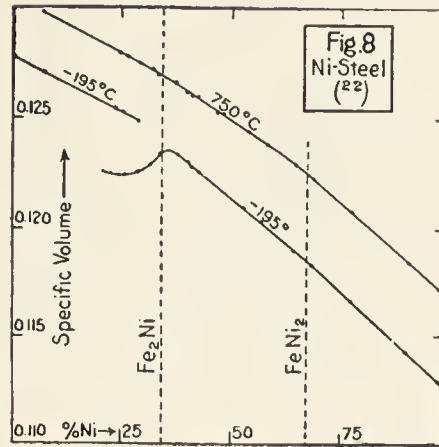
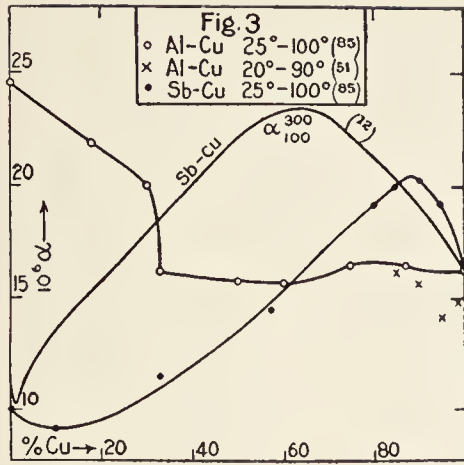
Fe-Cr-Mo-C; v. Table 28.

Fe-Cr-Si-C; v. Table 31.

Fe-Cr-V-C; v. Tables 28 and 29.

Fe-Cu-Cr-C; v. Table 28.





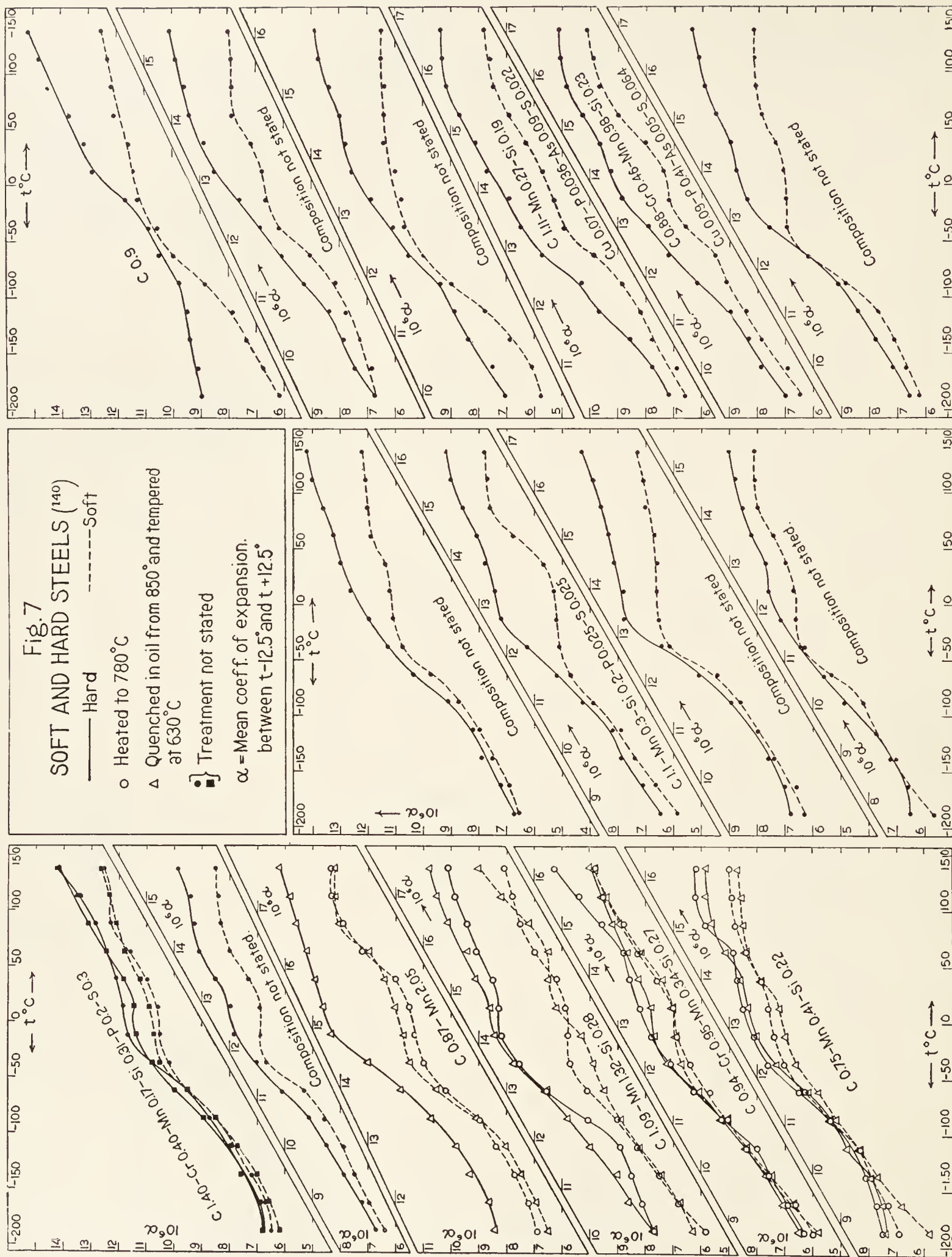




TABLE 4.—GENERAL TABLE.—(Continued)

Fe-Mn-C; *v. also* Tables 24 and 31

% composition	Ind. No.	Range, °C	10 <sup>6</sup> $\alpha$	10 <sup>3</sup> $\beta$ and 10 <sup>12</sup> $\gamma$	Lit.
Fe with Mn, < 10....	855	800	19.6-23.8		
Fe with Mn, 11.2.....	855	0 to 38	14.97	22.9 $\beta$	(61)
Fe with Mn, 14.....	855	0 to 1000	24.5		(84)

Fe-Mo-C; *v. also* Table 30

Fe with Mo, > 1.58...	906	100 to 700	11.8-16.3		(77)
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Fe-Ni; *v. also* Tables 25, 27 and Figs. 8-13

Fe with Ni, < 35....		20 to 900	11.3-16.9		
Fe with Ni, 35-100...		0 to 800	10-18		
Fe with Ni, 36.1; made by Société Genevoise; <i>v. Table 27</i> ("Invar")	727	-200 to -20	0.25	$\begin{cases} -4.97\beta \\ -6.13\gamma \end{cases}$	(137)
		-200	1.53		Comp.*
		-100	1.06		Comp.*
		-50	0.70		Comp.*
		-20	0.44		Comp.*
		0 to 100	1.5		(20, 127)
		100 to 200	2.8		(127)
		200 to 250	4.8		(127)
Fe with Ni, 36.1; Mn, 0.39; Cu, 0.39 ("Invar")	727	250 to 300	9.6		(127)
		300 to 400	13.7		(127)
		400 to 500	16.1		(127)
		500 to 600	17.7		(127)
		600 to 700	19.1		(127)
		750	20.3		(127)

\* Computed, using above values of  $\alpha$ ,  $\beta$ ,  $\gamma$ .

Fe with Ni, 31.4....		0 to 38	3.395	8.85 $\beta$	(58, 63)
Fe with Ni, 34.6....		0 to 38	1.373	2.37 $\beta$	(58, 63)
Fe with Ni, 35.6....		0 to 38	0.877	1.27 $\beta$	(58, 63)
Fe with Ni, 37.3....	727	0 to 38	3.457	-6.47 $\beta$	(58, 63)
Fe-Ni, 34.8; Cr, 1.5.		0 to 38	3.580	-1.32 $\beta$	(58, 63)
Fe-Ni, 35.7; Cr, 1.7.		0 to 38	3.373	1.65 $\beta$	(58, 63)
Fe-Ni, 36.4; Cr, 0.9.		0 to 38	4.433	-3.92 $\beta$	(58, 63)

Fe-Ni-C; *v. Tables 25, 26, 27, 28 and Figs. 8-13.*Fe-Ni-Cr-C; *v. Tables 28, 29.*Fe-Ni-Cr-Mo-C; *v. Table 29.*Fe-Ni-Si-C; *v. Table 31.*Fe-Ni-V-C; *v. Table 28.*Fe-Si; *v. Table 31.*Fe-V-C; *v. Table 28.*Fe-X-Y-C (Alloy Steels); *v. Tables 28, 29, 30.*Fe-W-C; *v. also* Table 30

Fe with W, 1.7-2.2....	1416	100 to 700	12.0-16.2		(77)
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Fe-W-Cr-C; Fe-W-Cr-Mo-C; etc. (High Speed Steels); *v. Table 30.*Hg-Ag-Sn-Cu-(Zn); *v. Table 33.*Mn-Si-Fe; *v. also* Table 31

Mn, 68; Si, 19.55; Fe, 11.6.....		15 to 900	18.27		(2)
Same, Tp 600° Q <sub>w</sub> 15°.		15 to 900	16.75		(2)

Mo (Commercial); *v. Table 34.*Ni (Commercial); *v. Table 35.*Ni-Cr; *v. also* Fig. 5

Ni, 90; Cr, 10.....	190	0 to 1000	12.80	4.33 $\beta$	(27)
Ni, < 85; Cr, > 15....		0 to 900	12.8-20.8		
Ni, 87; Cr, 9; Fe, 1.5; etc.....	949	0 to 38	12.34	6.02 $\beta$	(61)
Ni, 85; Cr, 10; Fe, 3; etc.....	949	0 to 38	12.63	8.77 $\beta$	(61)

Ni-Fe-Cr

Ni, 60; Fe, 26; Cr, 12; C, 0.6; Si, 0.4; Mn, 1.0 (cast).....	949	20 to 100	12.1		(67)
Ni, 60; Fe, 25; Cr, 12 (Dc).....	949	20 to 100	11.6		(67)

Ni-Fe-Si; *v. Table 36.*Ni-Cu-Fe-Mn; *v. also* Table 14

Ni, 67; Cu, 28; (Fe, Mn, Si, etc.) 5; <i>v. Table 14</i>	908	25 to 100	13.7-14.5		(129)
		25 to 300	14.9-15.2		(129)
		300 to 600	16.6-18.4		(129)
		25 to 600	15.9-16.7		(129)

TABLE 4.—GENERAL TABLE.—(Continued)

Ni-Cu-Fe-Mn.—(Continued)

% composition	Ind. No.	Range, °C	10 <sup>6</sup> $\alpha$	10 <sup>3</sup> $\beta$ and 10 <sup>12</sup> $\gamma$	Lit.
Ni, 66.58; Cu, 29.57; Fe, 1.79; Mn, 1.78; C, 0.15; Si, 0.09; S, 0.03; R <sub>h</sub> wire, typical sample	909	0 to 600	13.8	$\begin{cases} 3.375\beta \\ 0.83\gamma \end{cases}$	(129)
		0 to 100	14.1		Comp.*
		100 to 200	14.8		Comp.*
		200 to 300	15.6		Comp.*
		300 to 400	16.5		Comp.*
		300 to 600	17.3		Comp.*

\* Computed, using above values of  $\alpha$ ,  $\beta$ ,  $\gamma$ .Ni-Cu-Mn; *v. Table 14.*Ni-Fe; *v. Fe-Ni.*Ni-Si; *v. also* Table 36

Ni, 80.6; Si, 16.2; Fe, 2.5.....	1243	15 to 1000	12.20		(2)
Same, Tp 1000° Q <sub>w</sub> 15°		15 to 1000	13.37		(2)
Ni, 75; Si, 17.01; Fe, 7.6.....	1243	15 to 1000	12.35		(2)
Same, Tp as above....		15 to 1000	13.20		(2)
Ni, 39; Si, 17.86; Fe, 28.3.....	1243	15 to 1000	16.88		(2)
Same, Tp 600° Q <sub>w</sub> 15°		15 to 1000	12.39		(2)

Ni-Si-Fe; *v. Table 36.*Pb-Bi; *v. Table 38.*Pb-Cd; *v. Table 38.*Pb-Sn; *v. also* Table 38

Pb, 100; Sn, 0.....		15 to 110	29.3		(113)
Pb, 90.29; Sn, 9.71....		15 to 110	27.9		(113)
Pb, 87.5; Sn, 12.5....		15 to 110	27.45	SnPb <sub>4</sub>	(113)
Pb, 81.64; Sn, 18.36...		15 to 110	26.6		(113)
Pb, 71.64; Sn, 28.36...		15 to 110	25.8		(113)
Pb, 61.98; Sn, 38.02...		15 to 110	24.7		(113)
Pb, 52.09; Sn, 47.91...		15 to 110	23.8		(113)
Pb, 42.07; Sn, 57.93...		15 to 110	21.7		(113)
Pb, 32.82; Sn, 67.18...		15 to 110	21.6		(113)
Pb, 30.5; Sn, 69.5....		15 to 110	21.6	Sn <sub>4</sub> Pb	(113)
Pb, 22.53; Sn, 77.47...		15 to 110	21.4		(113)
Pb, 8.72; Sn, 91.28...		15 to 110	20.6		(113)
Pb, 0; Sn, 100 .....		15 to 110	21.8		(113)

Pt-Ir

Pt, 90; Ir, 10.....		0 to 38	8.651	1.00 $\beta$	(5, 58)
		0 to 1000	8.841	1.306 $\beta$	(31)
Pt, 80; Ir, 20.....		-190 to 16	7.502		(68)
		0 to 1000	8.198	1.42 $\beta$	(74)

Pt-Rh

Pt, 80; Rh, 20.....		0 to 1500	8.79	1.61 $\beta$	(31)
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Sb-Cu; *v. Cu-Sb and Fig. 3.*Si-Cu; *v. Cu-Si and Table 15.*Si-Fe (Industrial Ferro-silicon); *v. also* Table 37

Si, 75; Fe.....		15 to 1000	5.45		(2)
Si, 50; Fe.....		15 to 1000	16.23		(2)
Si, 32; Fe.....		15 to 1000	13.97		(2)
Si, 17.02; Fe.....		15 to 1000	14.45		(2)

Sn-Au; *v. Table 38.*Sn-Bi; *v. Table 38.*Sn-Pb; *v. Pb-Sn; v. also* Table 38.Sn-Zn; *v. Table 38.*Zn-Al; *v. also* Tables 9 and 10, and Fig. 4

Zn, 95; Al, 5 to Zn.		20 to 100	24.3-33.3		(70)
14; Al, 86		20 to 200	27.3-37.2		(70)
		20 to 300	28.3-40.7		(70)
Zn, 100-0; Al, 0-100		25 to 250	27.1-32.6		(128)
		20 to 250	27.7-38.2		(125)

Zn-Cu; *v. Fig. 6.*

TABLE 5.—AL-CU (70)

% composition					10 <sup>6</sup> $\alpha_{11}^2$					100 $\frac{\Delta l}{l}$ after test
Al	Cu	Si	Fe	Mn	20 to 100°C	20 to 200°C	20 to 300°C	20 to 400°C	20 to 500°C	
95.4	3.75	0.30	0.36	0.18	23.7	24.6	27.2	26.7	27.5	0.02
93.4	5.81	0.36	0.42		23.8	24.9	27.8	27.8	28.0	0.07
91.1	7.68	0.39	0.46	0.33	23.7	26.3	28.0	26.6	27.4	0.05
91.1	7.87	0.33	0.45	0.22	23.4	26.8	28.0	26.6	27.2	0.04
89.2	9.95	0.39	0.44		22.4	24.2	28.3	27.3	27.7	0.11
87.3	11.88	0.39	0.43		22.4	24.1	28.6	27.5	27.6	0.11

TABLE 6.—AL-CU-MG-SI (DURALUMIN) (70)

Treatment	% composition						$10^6 \alpha_{t_1}^{t_2}$						$100 \frac{\Delta l}{l}$ after test
	Al	Cu	Mg	Mn	Fe	Si	20 to 100°C	20 to 200°C	20 to 250°C	20 to 300°C	20 to 400°C	20 to 500°C	
Sand cast.....	94.8	3.68	0.36	0.57	0.35	0.25	23.4	24.7	25.7	26.0	26.7	27.5	+0.02
R <sub>h</sub> (ca. 410°) 3.5 to 0.25 in. thick	94.4	3.74	1.08		0.52	0.30	23.8	24.7	25.3	25.7	26.3	27.2	+0.03
R <sub>c</sub> W 520° Q <sub>w</sub> V 120°/2 d.....	94.4	3.74	1.08		0.52	0.30	23.7	25.2	25.8	26.4	27.3	27.3	-0.01
R <sub>d</sub> (contains 0.20 % Ca).....	94.6	3.66	0.52	0.51	0.37	0.16	23.1	26.0	26.6	26.8			+0.06
Same, reheated.....							22.3	24.0	24.4	25.0	25.9	25.7	+0.02
Same, Tp 500°, Q.....							23.2	24.1	25.3	26.0			+0.03
Same, reheated and quenched..	94.6	3.66	0.52	0.51	0.37	0.16	22.2	23.5	24.3	25.1	26.1	26.6	+0.05

TABLE 7.—AL-CU-MN; AL-CU-SI; AL-MN; AL-MN-CU; AL-SI-CU;  
AL-SI-CU-MN (70)

% composition					$10^6 \alpha_{t_1}^{t_2}$					
Al	Mn	Cu	Si	Fe	20 to 100°C	20 to 200°C	20 to 250°C	20 to 300°C	20 to 400°C	20 to 500°C
97.8	1.05	0.19	0.41	0.57	23.7	25.6	26.0	25.7	26.3	{ 27.4 28.5*
96.7	1.80	0.23	0.40	0.84	23.1	24.3	24.9	25.6	26.1	{ 27.2 27.9*
96.2	1.08	1.91	0.30	0.51	23.6	25.2	26.7	26.9	26.8	27.5
93.9	0.01	2.20	3.33	0.55	23.4	23.9	24.2	24.4		
89.6		2.43	7.42	0.53	21.7	22.5	23.0	23.4		
87.1		2.33	9.96	0.60	20.7	21.7	22.2	22.7		
91.3		4.41	3.75	0.57	22.4	23.4	23.8	24.1		
88.3		4.53	6.61	0.57	21.5	22.3	22.8	23.1		
88.7		6.62	4.08	0.64	21.8	22.9	23.4	23.6		
83.7		6.29	9.45	0.53	20.6	21.6	22.0	22.2		
84.6		4.58	10.28	0.54	20.4	21.3	21.8	22.1		
93.0	0.93	2.40	3.12	0.55	22.2	23.4	23.7	23.8		
86.4	0.82	2.32	9.97	0.50	20.4	21.5	22.0	22.4		
85.8	0.89	2.49	10.22	0.56	20.8	21.5	22.0	22.3		
85.6	1.17	2.47	10.18	0.70	20.4	21.5	22.0	22.3		

\* 20 to 600°.

TABLE 8.—AL-SI (70)

% composition				$10^6 \alpha_{t_1}^{t_2}$						$100 \frac{\Delta l}{l}$ after test
Al	Si	Fe	Cu	20 to 100°C	20 to 200°C	20 to 300°C	20 to 400°C	20 to 500°C	300 to 600°C	
95.0	4.15	0.52	0.33	22.2	23.2	24.1				-0.01
92.0	7.28	0.47	0.27	21.8	22.8	23.5				0.00
89.5	9.81	0.50	0.22	21.1	21.9	22.9				0.00
86.8	12.55	0.56	0.08	{ 19.4 21.1*	21.2 21.7	24.6 22.4	24.5 22.9	24.4 23.0	24.3 23.9	+0.09 +0.02
86.8†	12.55	0.56	0.08	19.5	20.5	22.2	22.9	23.0	24.1	-0.01

\* The values in this horizontal row were obtained on a second heating.

† This alloy, containing 86.81 % Al, etc., is modified by the addition, just before casting, of 0.1 % metallic sodium, in accordance with the process described by J. D. Edwards in U. S. Patent No. 1 410 461.

TABLE 9.—AL-ZN (70)

% composition						$10^6 \alpha_{t_1}^{t_2}$				$100 \frac{\Delta l}{l}$ after test
Al	Zn	Cu	Si	Fe	Mn	20 to 100°C	20 to 200°C	20 to 250°C	20 to 300°C	
85.83	12.17	1.47	0.21	0.31	0.01	{ 24.3 25.5 27.5	28.1 27.3 29.6	28.3 28.5	27.9* 28.3	+0.01
22.57	77.22	0.05	0.05	0.11	Nil	26.0†	28.3	30.5		+0.02
5.29	94.66	0.02	0.01	0.02	Nil	{ 33.3 32.0†	35.7 37.2	40.7		-0.01 +0.02

\* From 20 to 400°,  $10^6 \alpha$  is 27.6; from 20 to 500°,  $10^6 \alpha$  is 28.6.

† The values given in this horizontal row were obtained on a second heating.

TABLE 10.—AL-ZN;  $10^6 \alpha_{t_1}^{t_2}$  BETWEEN 20 AND  $t^\circ\text{C}$  (125)

Al-Zn alloys having 37.5–87.5 % Zn exhibit anomalous expansion above 250°C. The italicized values indicate results obtained on cooling, where different from those on heating.

For 100 % Al,  $\alpha_t = (23.0 + 0.014t) 10^{-6}$   
 For 100 % Zn,  $\alpha_t = (35.4 + 0.020t) 10^{-6}$  cf. Table 1.

TABLE 10.—AL-ZN;  $10^6 \alpha_{t_1}^{t_2}$  BETWEEN 20 AND  $t^\circ\text{C}$  (125)  
(Continued)

$t, ^\circ\text{C}$	% Zn									
	0	12.5	25	37.5	50	62.5	75	87.5	100	
100	23.6	23.9	26.1	26.6	26.5	26.1	27.1	26.4	36.4	
200	24.5	24.8	27.0	27.5	27.6	27.4	28.5	29.1	37.6	
230			27.6				29.6			
240			27.6				29.7			
250		{ 27.7 27.6	27.7	28.9	29.3	29.8	30.4	30.7	38.2	
260				30.1	30.8	30.0	38.0			
264				30.6	33.4				38.3	
266							{ 31.5 36.9			
270			{ 27.7 27.8	29.0	30.3	30.7	30.6	31.5	38.3	
280				30.8	33.9	36.7	38.5	38.0		
285				30.9	33.8	36.7	38.6			
290			27.8		33.6	36.8	39.0	38.7	38.5	
300	25.2	25.9	28.0	30.3	33.7	36.5	39.0		38.6	
400	25.9	27.1	29.1							

TABLE 11.—C (GRAPHITE)

The most reliable determinations of the expansion of graphite give results differing widely, probably owing to the differences in physical condition of the specimens used in the determinations.

Description of sample	Composition and treatment	Range, °C	$10^6 \alpha$	$10^6 \beta$	Lit.
Electric-arc carbon from H. Moissan.	99.97 % C $d_4^{18} = 2.216$ after being compressed to (5–10) $10^3$ kg/cm <sup>2</sup>	-163 to -38	7.2		
		-38 to 18	2.7		(29)
Acheson graphite....	Longitudinal	0 to 1500	0.55	1.6	(33)
	Transverse	0 to 400	2.4*		(71.1)
Earlier determinations:					
Batongol graphite....		10 to 90	7.5	5	(50)
Siberian graphite....	98 % C, $d = 1.8$	20 to 300	3.8		(99)

\* Partial report on research in progress (1926).

TABLE 12.—CO-CR-W-C (STELLITE) (129)

No.*	Approximate composition, % Co-Cr-W	$10^6 \alpha_{t_1}^{t_2}$									
		20 to 100°C	100 to 200°C	200 to 300°C	300 to 400°C	400 to 500°C	500 to 600°C	20 to 300°C	300 to 600°C	20 to 600°C	
1	80–20	14.1	15.1	16.2	15.9	16.0	18.9	15.2	16.9	16.1	
2	55–40–3†	13.4	15.2	16.0	16.3	17.5	20.2	15.0	18.0	16.5	
3	55–40–3†	12.2	13.1	13.7	14.3	15.4	17.9	13.2	15.8	14.6	
4	55–35–10	11.0	12.3	13.6	13.8	13.3	16.9	12.4	14.7	13.6	
4	55–35–10	Between -94 and +14°C $\alpha_{t_2}^{t_1} = 10.2 \times 10^{-6}$									

\* Description: 1. Soft, malleable. 2. Hard, malleable. 3. Hard malleable, hammered. 4. Stellite No. 2.

† Alloy contains 2 % C.



TABLE 13.—Cr-Fe-C-Si AND Cr-Fe-Si-C (2)

Composition and treatment	No. Range, °C	$10^6 \alpha_{t_1}^{t_2}$						
		1	2	2a	3	3a	4	4a
1. Industrial Cr, 48; Fe, 30; Si, 17; C, 5	15 to 100	10.23	8.00	9.17	7.52	9.29	7.52	7.17
2. Industrial Cr, 47.6; Fe, 47.1; C, 2.84; Si, 2.2	100 to 200	8.89	8.49	8.68	7.79	7.88	6.49	6.28
2a. Same Tp at 1000° in H <sub>2</sub> O at 15°C	200 to 300	9.58	8.38	9.18	7.68	8.58	7.29	6.88
3. Industrial Fe, 46.5; Cr, 45.9; C, 6.67; Si, 0.95	300 to 400	11.17	10.07	9.87	10.37	9.87	8.18	8.38
3a. Same Tp at 1000° in H <sub>2</sub> O at 15°C	400 to 500	11.85	11.36	11.95	10.06	9.46	9.37	9.37
4. Cr, 53.3; Fe, 39.1; C, 6.21; Si, 0.93	500 to 600	12.43	11.94	10.94	10.55	9.75	10.46	8.96
4a. Same Tp at 1000° in H <sub>2</sub> O at 15°C	600 to 700	12.91	12.82	13.42	11.83	10.74	10.94	8.16
	700 to 800	13.49	13.30	12.90	11.92	10.42	11.43	10.24
	800 to 900	13.18	11.80	10.31	11.21	8.93	10.12	8.63
	900 to 1000	13.46	11.58	11.78	11.89	8.82	11.10	9.82
	15 to 1000	11.75	10.62	10.86	10.12	9.39	9.32	8.41

TABLE 14.—Ni-Cu-Fe-Mn (MONEL METAL) (129)

% composition								Treatment	$10^6 \alpha_{t_1}^{t_2}$					
Ni	Cu	Fe	Mn	C	Si	S	Pb		25 to 100°C	100 to 200°C	200 to 300°C	300 to 400°C	400 to 500°C	500 to 600°C
60.05	32.46	2.21	2.00	0.15	0.87	0.035	2.22	Cast.....	13.9	15.0	15.8	16.8	17.7	20.6
								Heated to 900°C.....	14.3	15.0	15.7	16.7	18.1	18.3
66.18	28.42	2.37	2.10	0.18	0.70	0.038		Cast.....	13.7	15.1	15.7	16.6	17.7	18.5
								Heated to 900°C and cooled slowly.....	13.9	15.0	15.7	16.6	17.8	18.7
66.58	29.57	1.79	1.78	0.15	0.09	0.030		Hot rolled.....	14.2	14.9	15.5	16.7	17.0	18.1
								Same, heated to 870°C.....	14.3	15.3	15.8	16.5	17.4	17.7
67.32	28.73	1.74	1.66	0.31	0.19	0.035		Hot rolled.....	14.5	15.1	15.9	16.4	17.1	16.2
								Same, heated to 900°C.....	14.3	15.0	15.8	16.5	17.4	17.7
68.87	29.03	1.60	0.18	0.13	0.15	0.027		Hot rolled.....	14.2	14.7	15.6	16.4	17.6	17.9
								Same, heated to 870°C.....	14.0	15.0	15.9	16.4	17.3	18.1

TABLE 15.—Cu-Si; Cu-Si-Fe (2)

% composition and treatment	No. Range, °C	$10^6 \alpha_{t_1}^{t_2}$				
		1	2	3	4	5
1. Cu, 93.5; Si, 3.3; Fe, 2.6	15 to 100	15.41	10.58	12.10	14.94	6.58
2. Cu, 89.6; Si, 6.17; Fe, 3.7	100 to 200	12.19	12.88	15.08	14.28	4.49
3. Same Tp at 780°C	200 to 300	14.07	14.56	17.15	15.46	4.39
4. Cu-Si with Si, 10	300 to 400	14.65	18.83	18.52	16.73	4.39
5. Cu-Si with Si, 55	400 to 500	17.71	21.18	20.77	19.38	4.09
	500 to 600	20.46	21.83	19.93	15.57	3.79

TABLE 15.—Cu-Si; Cu-Si-Fe (2).—(Continued)

% composition and treatment	No. Range, °C	$10^6 \alpha_{t_1}^{t_2}$				
		1	2	3	4	5
1. Cu, 93.5; Si, 3.3; Fe, 2.6	600 to 700	20.72	21.88	20.29	15.85	5.88
2. Cu, 89.6; Si, 6.17; Fe, 3.7	700 to 800	21.86	20.15	22.03	32.94	4.18
3. Same Tp at 780°C	800 to 900	23.19	17.55	19.51		1.09
4. Cu-Si with Si, 10	900 to 1000					0.09
5. Cu-Si with Si, 55	15 to 1000					3.87
	15 to 900	17.88	17.83	18.49		
	15 to 700				16.08	

TABLE 16.—Cu-Zn (COLD ROLLED BRASSES) (69)

Metallurgical subdivision	Ind. No.	% composition					Range, °C	$10^6 \alpha$	$10^6 \beta$	$10^6 \alpha_t$ at				
		Cu	Zn	Sn	Pb	Fe				50°	100°	150°	200°	250°
$\alpha$ -Brass.....	1134	97.0	2.97		0.01	0.02	−49 to 301	16.48	3.63	16.84	17.21	17.57	17.93	18.30
	620	94.9	5.11		.01	.01	28 to 305	16.81	3.89	17.20	17.59	17.98	18.37	18.76
	401	90.3	9.70		.01	.03	26 to 302	17.01	3.79	17.39	17.77	18.15	18.53	18.90
	1182	85.2	14.76		.01	.02	−50 to 300	17.03	5.12	17.54	18.05	18.57	19.08	19.59
	799	80.0	19.89		.05	.03	28 to 302	17.22	5.90	17.81	18.40	18.99	19.58	20.17
	301	75.3	24.64		.02	.03	28 to 300	17.58	6.24	18.20	18.83	19.45	20.08	20.70
	1316	72.0	27.95		.01	.02	25 to 306	17.73	6.52	18.38	19.03	19.69	20.34	20.99
	336	70.3	29.66		.03	.03	19 to 301	17.75	6.53	18.40	19.06	19.71	20.36	21.02
$\alpha\beta$ -Brass.....	339	66.5	33.43		.04	.03	−50 to 301	18.26	5.61	18.82	19.38	19.94	20.50	21.06
		64.8	34.92		.24	.03	20 to 299	18.15	6.45	18.80	19.44	20.08	20.73	21.38
	400	63.6	36.17		.17	.03	21 to 299	18.11	7.25	18.84	19.56	20.28	21.01	21.74
	1409	62.1	37.71		.17	.02	23 to 308	18.05	8.55	18.90	19.76	20.62	21.47	22.32
Leaded brass $\alpha$ or $\alpha\beta$ .....	778	88.3	10.00	By difference	1.68	.02	21 to 301	17.06	3.89	17.45	17.84	18.23	18.62	19.00
	780	78.3	20.01		1.68	.03	22 to 301	17.48	5.24	18.00	18.53	19.05	19.58	20.10
	782	68.7	29.67		1.65	.03	20 to 304	17.91	6.52	18.56	19.21	19.87	20.52	21.17
	604	62.3	35.04		2.57	.06	21 to 302	18.26	6.56	18.92	19.57	20.03	20.88	21.54
$\alpha$ -Brass containing Sn.....	600	81.7	17.94	0.31	0.04	0.01	19 to 301	17.31	5.80	17.89	18.47	19.05	19.63	20.21
	16	70.6	28.21	1.10	.04	.01	20 to 301	17.94	6.93	18.63	19.33	20.02	20.71	21.40

TABLE 17.—Cu-Zn (MUNTZ METAL TYPE) (96)

% composition					$10^6\alpha_{t_1}^{t_2}$					
Cu*	Zn	Sn	Pb	Fe	20 to 100°C	100 to 200°C	200 to 300°C	300 to 400°C	400 to 450°C	500 to 600°C
65.6A	32.9	1.3	0.2	0.1	19.2	20.0	22.0	22.5	23.5	24.5
54.5B	43.9	1.3	0.1	0.2	21.6	21.8	22.8	29.6	35.0	30.5
54.7B	44.5	0.7	0.1	0.1	22.8	19.4	23.5	27.5	39.2	26.9
65.3A	34.5	0.23	0.2	Tr.	18.7	20.0	22.0	22.5	23.0	23.7
64.6A	35.4	0.06	0.04	<0.04	22.8	22.2	21.9	22.2	23.4	23.6
55.5B	44.5	0.07	0.05	<0.04	20.0	21.0	23.6	28.0	35.0	27.0

The transformation point, at which abnormal expansion of these brasses occurs, is about 460°C.

\* A =  $\alpha$ -Brass; B =  $\beta$ -Brass.

TABLE 18.—Fe-C (INGOT IRON, CAST IRON AND C-STEEL) (37)

% composition							Ind. No.	$10^6\alpha_{t_1}^{t_2}$				
C	Si	P	Mn	S	Ni + Co	Cu		0 to 250°C	0 to 375°C	0 to 500°C	0 to 625°C	0 to 750°C
0.14	0.07	0.42	0.44	0.03	0.53		1341	12.84	13.41	13.99		14.74
0.16		0.25	0.61	0.05	0.03	0.07	724	12.72	13.53	14.05		14.70
0.55	0.31	0.44	0.60	0.05		0.54	889*	12.48	13.17	13.79	14.37	13.29
3.22	1.68	0.46	0.71	0.08		0.48	661	11.18	11.98	12.58	13.93	
3.19	1.67	0.32	0.64	0.10	0.10	0.16	661	11.30	12.21	12.80		
3.59	1.18	0.04	0.46	0.06	0.04	0.13	661	11.34	12.12	12.88	13.35	14.22

0 to 875°C = 14.93

\* Cast.

TABLE 19.—Fe-C (C STEELS) (41)

## PERCENTAGE COMPOSITION OF ALLOYS

Sample	C	Mn	Si	P	S	Cu	Sample	C	Mn	Si	P	S	Cu
A	0.05-0.06	0.08	Tr.	Tr.	0.023	0.03	I	1.25	0.12	0.07	Tr.	0.019	0.02
B	0.09	0.08	0.02	0.01	0.01	0.01	J	1.45	0.14	0.10	0.01	0.013	0.04
C	0.22	0.12	0.01	0.01	0.03	0.04	K	1.67	0.17	0.11	0.01	0.013	0.04
D	0.33	0.12	0.03	0.01	0.03	0.03	L	1.97	0.15	0.08	Tr.	0.015	Tr.
E	0.40	0.11	0.07	0.01	0.03	0.03	M	2.24	0.15	0.08	Tr.	0.015	Tr.
F	0.56	0.09	0.04	Tr.	0.023	0.02	N	3.66	0.14	0.09	0.015	0.012	Tr.
G	0.65	0.12	0.09	0.01	0.03	0.03	O	3.80	0.16	0.05	0.015	0.01	Tr.
H	0.81	0.10	0.06	Tr.	0.025	0.02							

VALUES OF  $10^6\alpha_{t_1}^{t_2}$ 

Sample Range, °C	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
20 to 50	11.49	11.16	11.22	10.92	10.73	10.17	10.74	10.17	10.58	9.67	10.02	9.72	9.03	8.57	8.43
20 to 100	11.66	11.58	11.66	11.09	11.29	10.98	11.04	11.04	10.87	10.13	10.44	9.94	9.61	8.59	8.71
20 to 150	12.06	12.06	11.96	11.70	11.45	11.44	11.34	11.43	11.14	10.38	10.51	10.02		8.75	8.76
20 to 200	12.32	12.61	12.12	11.89	11.99	11.85	11.57	11.56	11.08	10.58	10.28	9.96	9.64	8.83	8.49
20 to 250	12.56	12.72	12.49	12.38	12.07	12.27	11.88	11.93	11.46	11.16	10.83	10.52	10.25	9.04	9.35
20 to 300	13.02	13.01	12.78	12.72	12.47	12.65	12.31	12.43	11.87	11.67	11.38	11.14	10.96	9.88	10.11
20 to 350	13.34	13.36	13.12	13.09	12.86	13.08	12.74	12.84	12.33	12.18	11.88	11.72	11.59	10.63	10.92
20 to 400	13.65	13.63	13.38	13.42	13.26	13.40	13.16	13.21	12.75	12.68	12.34	12.21	12.15	11.35	11.52
20 to 450	13.98	13.93	13.68	13.88	13.66	13.74	13.42	13.55	13.16	13.13	12.82	12.68	12.72	11.96	12.12
20 to 500	14.22	14.18	13.93	14.02	13.90	14.02	13.84	13.82	13.36	13.48	13.15	13.12	13.16	12.50	12.62
20 to 550	14.33	14.38	14.17	14.20	14.17	14.27	13.93	14.08	13.78	13.78	13.38			12.91	
20 to 600	14.64	14.64	14.38	14.43	14.36	14.50	14.20	14.22	13.99	14.04	13.66			13.23	
20 to 650	14.85	14.86	14.66	14.59	14.61	14.67	14.52	14.50	14.22	14.24	13.93			13.70	
20 to 700	15.01	15.03	14.81	14.76	14.76	14.81	14.65	14.67	14.41	14.42	14.24			13.92	
20 to 750	14.84	14.93													
20 to 800	14.67	14.61	12.93	11.33	11.72	12.46	12.68	14.22	14.78	15.13	15.02			14.13	
20 to 900	13.14	12.34	12.48	11.53	12.35	13.54	13.87	15.05	16.64	17.63	17.57			15.04	
20 to 1000	13.35	13.32	13.16	13.08	13.25	14.38	14.76	15.70	17.43	19.50	19.61			15.86	
700 to 1000	9.50	9.42	9.40	9.29	9.91	13.47	15.00	17.90	24.10	29.74	31.45			20.24	

TABLE 20.—Fe-C (C-STEEL RAILS) (18)

Bessemer rails			Open hearth rails		
% composition	$10^6\alpha_0^t$	$t, ^\circ\text{C}$	% composition	$10^6\alpha_0^t$	$t, ^\circ\text{C}$
C, 0.50-0.39	14.2	500	C, 0.66-0.70	14.4	500
S, 0.042-0.071	15.0	600	S, 0.033-0.057	14.7	600
P, 0.081-0.067	15.2	700	P, 0.028-0.025	14.9	700
Mn, 0.93-0.90	13.3	800	Mn, 0.66-0.72	14.3	800
Si, 0.101-0.035	14.0	900	Si, 0.160-0.079	15.0	900
Cu, 0.007-0.105	14.6	1000	Cu, 0.016-0.026	15.7	1000
Ni, 0.06-0.12	15.1	1100	Ni, 0.00	16.2	1100
Cr, 0.00-0.17			Cr, 0.01		

Abnormal expansion occurs between 700 and 800°C.

TABLE 21.—Fe-Cr-C (94)

## Containing 0.6% C

% Cr	Trans- formation temp., °C	$10^6\alpha_{100}$	$10^6\alpha_{500}$
0	790	11.5	15.9
0.5	785	11.9	15.6
1	777	11.3	14.8
2	787	11.8	14.3
3	802	12.1	14.8
5	830	11.0	13.9
10	837	10.1	13.1
20	845	10.0	12.0



TABLE 22.—Fe-Cr-C (STAINLESS STEEL) (129)

Range, °C	$10^6\alpha_{t_1}^{t_2}$		Composition
	Hard	Annealed	
20 to 100	9.6	10.3	Cr, 13.1
20 to 200	9.8	10.7	C, 0.3
200 to 400	9.9	12.3	Mn, 0.18
400 to 600	13.8	13.3	Si, 0.11
600 to 800	13.4	13.6	P, 0.02
20 to 600	11.2	12.1	S, 0.011

Abnormal expansion occurs between 825 and 855°C. The hardened steel also exhibits irregular expansion between 200 and 400°C.

TABLE 23.—Fe-Mn-C (KRUPP'S CARBON STEELS) (77)

% composition		$10^6\alpha_{15}^{75}$
C	Mn	
0.14	0.39	11.88
0.18	0.34	12.11
0.31	0.65	11.73
0.44	0.67	11.65
0.56	0.30	12.08
0.64	0.27	11.79
0.75	0.35	11.55
0.80	0.30	11.70
0.94	0.35	11.50
1.02	0.36	11.49
1.30	0.40	10.94
1.50	0.36	10.83

TABLE 24.—Fe-Mn-C (Mn STEELS) (93)

% Mn	$\alpha_{100}$		$\alpha_{500}$		$\alpha_{800}$
0.11	12.6	Austenite-martensitic	15.4	Austenite-martensitic	19.9
0.31	12.3		14.8		19.6
0.6	11.5		14.8		20.1
0.8	11.6		14.7		19.6
1.1	11.8		15.2		20.4
1.6	12.8		15.3		21.0
2.0	13.4		15.7		21.2
3.0	13.5		15.7		21.9
5.0	12.9		15.5		22.6
6.9	12.5		15.6		23.5
7.9	Pearlitic or martensitic	14.7	Pearlitic or martensitic	18.0	23.5
8.8		16.2		21.9	23.4
9.8		16.8		22.0	23.8

Anomalous expansion of these Mn steels begins at about 650°C.

TABLE 25.—Fe-Ni-C (Ni STEELS INCLUDING INVAR)

$t, ^\circ\text{C}$	% Ni			$10^6\alpha_t$ (82)	
	$10^6\alpha_0^{t_1}$ (87)			% Ni	$10^6\alpha_{20}$
	5	25	33		
50	9.44	14.72	-0.18	0	11.0
100	10.03	15.86	+0.09	10	13.0
150	10.59	16.75	0.80	20	19.5
200	11.01	17.40	1.93	30	12.0
250	11.33	17.81	3.50	36	0.9
300	11.55	17.98	5.50	40	6.0
				50	9.7
				80	12.5
				100	12.8

TABLE 26.—Fe-Ni-C (NICKEL STEELS CONTAINING 0.9% C) (134)

% Ni	$10^6\alpha_{t_1}^{t_2}$				
	20 to 100°C	20 to 300°C	20 to 500°C	20 to 700°C	20 to 900°C
3	13	11.1	10.7	11.1	11.4
4	12	11.1	10.5	10.5	11.3
6	11	11.8	10.8	8.2	13.7
10	9	9.6	9.3	7.1	12.9
12	8	8.5	8.2	7.7	14.2
15	8	9.3	9.0	8.6	14.6
20	8	10.4	9.4	8.8	14.4
25	11	11.2	10.6	8.5	13.6
30	9	12.4	9.4	11.4	14.8
35	1.2	7.7	12.0	13.8	16.9

TABLE 27.—Fe-Ni-C (INVAR STEELS) (58,63)

% Ni	Range, °C	$10^6\alpha_t = a + bt$	
		a	b
30.4	0 to 110	4.570	0.0235
	110 to 164	-4.29	0.104
	164 to 220	11.3	0.008
31.4	0 to 122	3.395	0.015
	122 to 182	-10.37	0.128
	182 to 220	6.44	0.036
34.6	0 to 142	1.373	0.0047
	142 to 220	-7.18	0.065
37.3	0 to 150	3.457	-0.0072
	150 to 220	0.72	0.011

Table 28. See p. 472.

TABLE 28A.—STEEL AND IRONS OF TABLE 28 ABOVE THE CRITICAL REGION (130)

No.	$10^6\alpha_{t_1}^{t_2}$				Increase in length at 25°C, $\mu/\text{m}$
	Heating	Temp. range, °C	Cooling	Temp. range, °C	
1	23.4	825 to 900	22.7	900 to 725	-1202
2			22.7	900 to 700	-462
3	22.7	800 to 900	22.7	900 to 800	-110
4	22.8	800 to 900	22.8	900 to 800	-82
5	24.0	800 to 900	23.1	900 to 725	-400
6	24.1	825 to 900	22.8	900 to 800	-270
7	24.0	825 to 900	22.6	900 to 800	-90
8			22.3	900 to 550	-680
9			21.9	900 to 800	-198
10			22.0	900 to 805	+343
11			23.0	895 to 820	-593
12					+98
13					+346
14	22.2	800 to 900	22.8	900 to 700	-727
15					+335
16					+18
17			22.7	900 to 800	-200
18	22.6	800 to 900	21.1	900 to 600	-920
19	23.0	800 to 900	23.0	900 to 800	-148
20					-63
21	22.6	800 to 900	23.1	900 to 800	-366
22	23.4	906 to 945	23.4	945 to 917	-120
23	34.0	750 to 875	28.6	875 to 713	
24	23.4	833 to 950	21.6	950 to 760	-430
25	37.0	815 to 900	25.0	900 to 775	+9040
27					0

TABLE 28.—Fe-C; Fe-Cr-C; Fe-Ni-C; Fe-Si-C; Fe-V-C (CARBON AND ALLOY STEELS, CAST IRON AND ELECTROLYTIC IRON) (130)

No.	% composition									$10^6\alpha_{t_1}^{t_2}$									
	C	Mn	P	S	Si	Cr	V	Ni	Miscellaneous	25 to 100°C	100 to 200°C	200 to 300°C	300 to 400°C	400 to 500°C	500 to 600°C	600 to 700°C	25 to 300°C	300 to 600°C	25 to 600°C
1	0.35	1.42	0.013	0.057	0.20	1.00	0.11			12.4	12.8	14.4	15.1	15.9	15.9	16.2	13.3	15.6	14.5
2	0.49	1.21	0.05	0.050	0.12					11.3	12.2	14.2	16.3	17.7	15.4	16.7	12.7	16.5	14.7
3	0.41	0.64	0.052	0.061	0.086					11.1	12.2	14.3	15.8	15.7	16.0	16.6	12.7	15.8	14.3
4	0.44	0.57	0.013	0.033	0.161		0.14			11.2	12.4	14.3	15.4	16.4	16.5	16.8	12.7	16.1	14.5
5	0.59	0.92	0.024	0.033	0.25					11.1	12.5	14.6	15.4	16.1	16.8	16.6	12.9	16.1	14.6
6	0.35	0.08	0.010	0.027	0.110	1.17	0.14			11.0	12.3	14.8	15.6	15.9	16.5	16.2	12.9	16.0	14.5
7	0.36	0.46	0.011	0.029	0.09	0.57	0.12			11.8	12.6	14.4	15.1	16.0	16.6	16.8	13.1	15.9	14.5
8	0.168	0.01	0.010	0.026	0.135	2.50	0.39	3.94		10.8	11.7	13.5	14.0	14.5	14.4		12.1	14.3	13.3
9	0.410	1.11	0.053	0.049	0.115			2.00		11.6	11.9	14.0	16.2	15.7	16.5	16.4	12.6	16.1	14.4
10	0.144	0.10	0.03	0.035	0.034	1.15	0.21		Cu, 1.85	11.2	12.6	13.8	15.6	15.6	16.0	16.7	12.7	15.7	14.3
11	0.252	0.06	0.012	0.035	0.007					11.1	12.0	14.2	15.5	15.9	16.6	16.9	12.5	16.0	14.3
12	0.168	0.08	0.010	0.029	0.038	0.92	0.24		Mo, 0.64	11.3	11.8	13.9	15.3	15.7	16.6	16.1	12.5	15.9	14.2
13	0.122	0.05	0.020	0.040	0.846	0.85	0.23			11.6	12.5	13.7	14.6	15.2	16.0	15.8	12.7	15.2	14.0
14	0.326	0.78	0.014	0.035	0.094			3.59		10.9	11.5	13.6	15.2	15.1	15.7		12.1	15.3	13.8
15	0.342	0.28	0.01	0.043	0.094	0.82	0.26		Cu, 2.70	11.6	12.6	14.2	16.0	15.9	16.4	16.9	12.9	16.1	14.6
16	0.396	0.25	0.012	0.023	0.095				W, 3.96	11.1	12.0	14.0	15.1	15.7	16.4	16.5	12.5	15.7	14.2
17	0.380	1.17	0.055	0.067	0.10			0.81		11.2	12.7	14.3	15.2	16.2	16.7	16.4	12.9	16.1	14.5
18	0.388	1.21	0.010	0.043	1.04			3.67		11.6	12.0	13.2	14.2	15.2	15.6		12.3	15.0	13.7
19	0.512	0.42	0.016	0.021	1.45				W, 1.58	10.4	12.1	13.7	15.9	15.7	16.1		12.2	15.9	14.2
20	0.30-0.40					13.00				10.0	10.6	12.0	12.6	13.5	13.9	13.7	11.0	13.3	12.2
21	0.418	0.68	0.012	0.025	0.23					9.4	12.0	14.3	15.3	16.4	17.1	16.8	12.1	16.2	14.3
22*	0.02	Nil	Nil	0.007	0.006	(Co, Cu, Ni, total 0.014)				12.0	13.0	14.5	15.3	15.9	16.8	17.4	13.3	15.9	14.7
23	1.28	0.37				0.19				11.0	11.6	13.6	15.1	16.3	16.1	17.0	12.0	15.9	14.1
24	0.20	1.10	0.05	0.05		0.5		0.5		12.3	12.9	14.2	15.9	16.2	16.5	16.8	13.2	16.5	14.9
25	3.08				1.68					8.4	11.7	14.2	15.6	14.3	Growing		11.6	Growing	
26	0.14							34.52		3.7	8.4	14.1	16.6	18.4	18.8	19.1	9.2	18.2	13.6
27	0.09	0.19			3.70	0.176	0.005-	0.05-		11.1	12.4	13.3	14.0	15.6	16.0	16.9	12.6	15.3	14.0

\* Vacuum electrolytic iron.

TABLE 29.—Fe-Cr-C; Fe-Cr-V-C; Fe-Ni-Cr-C (ALLOY STEELS) (92)

% composition							$10^6\alpha_{t_1}^{t_2}$	
C	Si	Mn	P	S	Cr	Ni	25 to 100°C	25 to 270°C
0.34	0.10	0.64	0.012	0.023	0.76	3.43	11.37	12.49
0.30*	0.11	0.66	0.025	0.005	0.86	3.05	11.67	12.57
0.50	0.15	0.64	0.015	0.031	0.88	1.90	11.72	12.70
0.32†	0.23	0.53	0.013	0.015	1.37	3.53	11.83	12.78
0.35	0.0	0.65	0.008	0.045	0.80	3.14	11.73	12.79
0.43	0.0	0.78	0.015	0.027	0.75	1.87	12.00	12.87
0.43‡	0.18	0.81	0.031	0.032	0.88	2.55	11.65	12.89
0.40§	0.14	0.76	0.006	0.012	1.20		11.60	13.04
0.34¶	0.17	0.72	0.009	0.010	0.96		11.76	13.10
0.44**	2.07	0.81	0.012	0.010			12.52	13.51
0.40††	0.57	0.78	0.011	0.015	0.78		12.76	13.83

\* Contains 0.53 % Mo.

|| Contains 0.17 % V.

† 830° Q<sub>o</sub> Tp 570°.¶ 930° Q<sub>o</sub> Tp 620°.

‡ Contains 0.07 % V.

\*\* 930° Q<sub>o</sub> Tp 590°.§ 930° Q<sub>o</sub> Tp 650°.†† 830° Q<sub>o</sub> Tp 590°.

TABLE 32.—Ag-Hg-Zn (131)

Ag-Zn amalgam					
% Ag	% Zn	$10^6\alpha_{20}^{50}$	% Ag	% Zn	$10^6\alpha_{20}^{60}$
68	0	25.4	67	2	28.0
68	1	25.9	60	5	24.5
67	1	26.4	54	0	23.4

TABLE 33.—Hg-Ag-Sn-Cu-(Zn), AG-SN-CU AMALGAMS (54)

Composition of amalgam alloys						Alloy	Hg-alloy ratio	$10^6\alpha_{37.5}$
	A	B	C	D	E			
Ag.....	68	68	70	70	54	B	2.00	25.2-26.8
Sn.....	27	26	27	27	30	B	1.60	24.8-25.2
Cu.....	5	5	3	3	16	D	2.00	27.7
Zn.....	0	1	0	1	0	C	2.00	27.8-28.5
Total..	100	100	100	101	100	A	1.60	26.0-29.3
						E	1.60	24.3-26.8

Alloy D was made by the addition of 1% Zn to the alloy of composition C.

TABLE 30.—Fe-Mo-C; Fe-W-C; Fe-W-Cr-C (ALLOY STEELS) (77)

% composition									Ind. No.	$10^6\alpha_t$ at						
C	Si	Mn	P	S	Cr	W	Mo	V		100°C	200°C	300°C	400°C	500°C	600°C	700°C
0.82	0.18	0.26	0.003	0.016	3.71	14.63	0.17	0.20	285	10.0	11.6	12.5	13.2	13.75	14.2	14.4
.47	.56	.16	.014		1.03	1.17			748	11.5	12.3	13.2	14.25	15.25	16.4	17.75
.64	.05	.01	.015	.012	3.73	14.06		0.11	942	11.1	11.9	12.6	13.2	13.65	13.9	14.0
.66	.08	.08	.018	.016	3.43	16.81		0.11	1435		10.8	11.7	12.4	13.1	13.6	
.73					3.90	13.50			284	10.7	11.75	12.75	13.5	14.1	14.25	
.69	.24	.20	.016	.016		6.31			283	9.8	12.65	14.5	15.5	16.1	16.55	
.59	.22	.06	.028	.023	2.86	18.81			1015		12.15	13.2	13.75	14.3	14.75	
.63	.58	.22	.009	.024					906		11.8	12.8	13.75	14.6	15.4	
.55	.25	.71	.036	.003					906		12.2	13.6	14.6	15.5		
.33	.13	.23	.038	.011		1.71			1416		12.4	13.3	14.1	15.0	16.0	17.2
.45	.15	.22	.022	.011		2.20			1416		12.3	13.1	14.0	15.0	16.2	17.55
.38	.13	.24	.022	.011		2.07			1416		12.35	13.1	13.8	14.75	15.7	16.85
.36	.19	.26	.023	.013		1.84			1416		12.0	12.9	13.8	14.8	16.0	



TABLE 31.—Fe-Cr-Si; Fe-Mn-Si; Fe-Ni-Si; Fe-Si (STEELS CONTAINING SI, AND FERRO-SILICON) (2) (*v. also* Tables 36, 37)

% composition							Range, °C Ind. No.	$10^6 \alpha_{t_1}^{t_2}$											
Fe	Cr	Mn	Ni	Si	C	P		15 to 100°	100 to 200°	200 to 300°	300 to 400°	400 to 500°	500 to 600°	600 to 700°	700 to 800°	800 to 900°	900 to 1000°	15 to 900°	15 to 1000°
92.4	3.12	0.0	0.0	0.56	2.66		1235	10.23 * 9.52	10.89 8.78	13.57 13.67	14.65 21.03	16.02 4.57	15.99 11.83	15.37 16.38	10.10 8.42	23.25 18.92	27.24 28.97	14.53 12.61	
89.5	7.4	0.0	0.0	2.38	1.62		1235	10.94 * 9.41	10.49 10.29	12.07 10.68	14.55 12.56	16.02 13.24	18.18 12.63	16.26 14.90	17.92 18.64	17.00 26.53		14.90 14.40	
85†	0.0	9.33	0.0	1.91	3.63			16.00 *12.70	11.89 14.28	13.57 15.26	17.64 18.42	19.60 20.38	19.66 17.16	14.96 15.35	19.49 18.59	20.25 16.78	11.73 15.66		16.53 16.54
11.6	0.0	68	0.0	19.6	0.65			13.05 ‡13.29	13.48 15.58	15.27 14.96	19.13 16.43	19.79 16.10	19.56 16.77	19.82 16.94	21.56 18.69	21.91 21.33		18.27 16.75	
85†	0.0	0.0	9.9	4.27	0.58			10.82 §10.47	11.98 11.89	14.36 12.37	17.73 11.86	11.93 14.63	11.92 8.84	12.99 11.02	20.61 12.75	25.61 20.30		15.41 13.29	
59†	0.0	0.2	22.6	6.93	0.35	0.9		11.05 §11.17	11.78 12.58	12.97 14.06	16.05 15.34	17.51 14.82	19.17 14.70	17.15 13.98	22.27 16.93	16.59 20.37		16.15 14.95	
93.7†	0.0	0.2	0.0	1.65	3.04	1.3	661	8.47 *10.00	9.29 7.39	10.87 8.58	12.76 14.16	12.94 14.54	14.32 3.68	13.90 13.02	16.46 17.47	19.01 27.65	14.62 23.03		13.34 14.02
83†				17				8.82 *10.35	10.19 10.89	11.67 12.57	14.25 14.15	15.73 14.63	17.09 15.20	16.47 15.77	16.94 18.33	15.33 14.73	17.18 17.57		14.45 14.49
68†				32				12.11	11.18	12.87	13.45	15.02	14.70	14.48	15.06	14.24	16.00		13.97

\* Values on this line for alloy: Tp 1000° Q<sub>w</sub> 15°. † By difference. ‡ Tp 600° Q<sub>w</sub> 15°. § Tp 900° Q<sub>w</sub> 15°.

TABLE 34.—Mo (COMMERCIAL PURE) (71)

No.	Description	% composition				10%α <sub>t<sub>1</sub></sub> <sup>t<sub>2</sub></sup> (heating)									10%α <sub>t<sub>1</sub></sub> <sup>t<sub>2</sub></sup> (cooling)			100 $\frac{\Delta l}{l}$ after test
		Fe	Si	Ca	W	25 to 100°C	100 to 200°C	200 to 300°C	300 to 400°C	400 to 500°C	25 to 250°C	250 to 500°C	25 to 500°C	500 to 25°C	500 to 250°C	250 to 25°C		
1	Ingot, from fine powder.....					5.4	5.1	5.2	5.6	5.7	5.3	5.5	5.4	5.6	5.8	5.3	-0.010	
2	No. 1 swaged to 0.25 in. diam.....	0.03	0.03		1.85	4.9	5.1	5.4	5.7	7.4	5.1	6.3	5.8	5.8	5.9	5.6	-0.001	
3	No. 2 swaged to 0.175 in. diam.....	0.05	0.014	0.005	1.80	4.9	5.1	5.2	5.4	6.2	5.1	5.7	5.4	5.5	5.8	5.3	-0.007	
4	No. 3 swaged to 0.1 in. diam.....					4.6	4.8	5.2	5.9	6.4	4.8	6.0	5.4	5.0	5.3	4.6	+0.022	
5	Ingot, from coarse powder.....	0.04	0.003			3.7	5.5	4.8	5.8	5.8	4.6	5.7	5.2	5.4	5.7	5.1	-0.009	
6	Similar ingot to No. 5.....					5.0	5.0	5.2	5.0	3.4	5.1	4.4	4.7	5.5	6.0	4.9	-0.036	
7	No. 6 swaged to 0.25 in. diam.....				Cu	4.8	4.8	5.2	6.4	7.0	4.9	6.4	5.7	5.5	5.7	5.3	+0.009	
8	No. 7 swaged to 0.175 in. diam.....	0.11	0.003		0.014	4.5	4.6	5.1	5.1	6.5	4.7	5.6	5.2	4.8	5.5	4.1	0.017	
9	No. 8 swaged to 0.1 in. diam.....	0.03	0.004		0.006	4.5	4.3	4.4	6.1	7.2	4.4	6.2	5.3	5.1	5.3	4.8	0.012	
10	Ingot, from coarse powder and swaged to 0.25 in. diam.....	0.10	0.017	0.005		4.6	4.9	5.2	6.5	7.0	4.8	6.5	5.7	5.2	5.3	4.9	0.026	
11	No. 10 swaged to 0.175 in. diam.....					4.8	5.1	5.4	5.9	6.7	5.0	6.1	5.6	5.6	6.0	5.1	0.002	
12	No. 11 swaged to 0.1 in. diam.....	0.11	0.007	0.010	0.005	3.7	4.7	4.9	4.9	5.8	4.5	5.2	4.9	4.0	3.8	4.2	0.043	

TABLE 35.—Ni (COMMERCIAL PURE) (130)

% composition							Treatment	$10^6 \alpha_{t_1}^{t_2}$								
Ni	Cu	Fe	Mn	C	Si	S		25 to 100°C	100 to 200°C	200 to 300°C	300 to 400°C	400 to 500°C	500 to 600°C	25 to 300°C	300 to 600°C	25 to 600°C
99.06	0.12	0.37	0.19	0.12	0.12	0.027	Hot rolled.....	13.2	14.4	15.3	16.8	15.5	16.9	14.4	16.4	15.4
							Annealed 1 hr at 870°C...	13.3	14.5	15.4	16.4	16.6	16.3	14.5	16.5	15.5
99.02	.12	.37	.22	.08	.16	.020	Hot rolled.....	12.9	14.5	15.4	16.9	16.5	16.8	14.4	16.7	15.6
							Annealed 1 hr at 900°C...	13.3	14.5	15.5	16.7	16.3	16.9	14.5	16.6	15.6
98.76	.17	.38	.18	.22	.26	.020	Hot rolled.....	13.0	14.2	15.7	15.9	15.7	14.4	14.4	15.3	14.9
							Annealed 1 hr at 900°C...	13.3	14.2	15.6	16.3	16.2	16.3	14.5	16.3	15.4
97.05	.15	.44	2.08	.09	.15	.029	Hot rolled.....	13.1	13.5	14.8	17.2	16.6	17.1	13.8	17.0	15.5
							Annealed 1 hr at 870°C...	13.5	14.3	15.8	16.0	16.6	17.3	14.6	16.6	15.7
94.21	.14	.46	4.92	.12	.10	.030	Hot rolled.....	13.2	14.1	15.4	15.9	16.7	17.3	14.3	16.7	15.5
				Co			Annealed 1 hr at 870°C...	13.3	14.1	15.4	15.9	16.6	17.6	14.3	16.7	15.6
97.0*	.3	.8	1.6	<1				$\alpha_{25}^{200}$ , 14; $\alpha_{200}^{400}$ , 16; $\alpha_{400}^{600}$ , 16; $\alpha_{600}^{840}$ , 20; $\alpha_{25}^{840}$ , 17†								

No marked abnormality is shown between 300 and 400°C by first 5 samples; cf. pure Ni in Table 1.

\* Spark plug electrodes (133). † These values are for  $10^6 \alpha_{t_1}^{t_2}$ .

TABLE 36.—Ni-Fe-Si; Ni-Si-Fe (2)

Composition and treatment	No. Range, °C	$10^6 \alpha_{t_1}^{t_2}$					
		1	1a	2	2a	3	3a
1. Ni, 80.6; Si, 16.2; Fe, 2.5 1a. Same, Tp 1000° Q <sub>w</sub> 15° 2. Ni, 75; Si, 17.01; Fe, 7.6 2a. Same, Tp 1000° Q <sub>w</sub> 15° 3. Ni, 39; Fe, 28.3; Si, 17.86; Mn, 13.1; C, 0.3 3a. Same, Tp 600° Q <sub>w</sub> 15°	15 to 100	8.58	8.82	8.58	8.82	11.29	9.17
	100 to 200	9.09	11.19	9.19	10.29	12.18	9.08
	200 to 300	9.58	9.88	9.98	11.37	15.46	8.18
	300 to 400	11.37	11.77	11.56	12.36	17.03	9.77
	400 to 500	13.25	13.95	12.76	13.74	17.70	12.95
	500 to 600	14.22	15.12	15.12	14.22	19.16	13.23
	600 to 700	14.10	16.09	14.6	14.00	20.71	16.40
	700 to 800	13.49	16.66	14.68	14.08	21.75	16.86
	800 to 900	12.48	15.34	13.47	14.06	17.66	15.05
	900 to 1000	15.33	14.93	13.05	18.39	14.87	12.66
	15 to 1000	12.20	13.37	12.35	13.20	16.88	12.39

TABLE 37.—Si-Fe-C (2)

Composition and treatment	No. Range, °C	$10^6 \alpha_{t_1}^{t_2}$			
		1	2	3	4
1. Cast Si with ca. 2 % of SiC + Tr. Fe-Si. Sudden increase in $\alpha$ between 700 and 805°; anomaly between 700 and 1000°	15 to 100	6.00	6.58	6.94	9.17
	100 to 200	5.18	5.39	4.79	8.78
	200 to 300	4.69	4.59	4.99	9.18
	300 to 400	4.29	4.19	4.89	10.07
	400 to 500	3.89	4.39	4.99	10.46
2. Industrial SiC (crystallized)	500 to 600	3.99	4.28	4.98	11.84
	600 to 700	4.88	4.18	5.68	13.52
3. Industrial Fe-Si with 75 % Si	700 to 800	10.46	4.38	6.67	47.36
	800 to 900	3.28	2.98	5.27	24.90
4. Industrial Fe-Si with 50 % Si	900 to 1000	0.19	2.68	4.27	15.96
	15 to 1000	4.68	4.35	5.45	16.23

TABLE 38.—COEFFICIENT OF CUBICAL EXPANSION OF ALLOYS IN THE RANGE 0 TO 100°C  $V_t = V_0[1 + At + Bt^2]$  (95)

Composition	$10^6 A$	$10^6 B$	Composition	$10^6 A$	$10^6 B$
Ag, 4; Au.....	51.66		Bi, 44; Sn.....	37.93	27.1
Ag, 71.6; Au, 28.4...	44.13	13.0	Sn, 2; Bi.....	49.97	10.1
Ag; Au.....	49.16		Cd; Pb.....	90.05	13.3
Ag, 36.1; Au, 63.9...	48.84	55.2	Cu, 71; Zn, 29...	51.61	55.8
Ag; Au, 4.....	31.15	118.5	Pb, 4; Sn.....	80.87	33.2
Ag, 2; Pt.....	42.46	32.2	Sn, 4; Pb.....	62.0	98.8
Au, 2; Cu.....	40.15	64.2	Sn, 7; Au, 2....	41.65	26.3
Bi, 24; Pb.....	38.68	21.8	Sn, 2; Au.....	39.44	28.9
Pb, 2; Bi.....	84.62	15.9	Sn, 6; Zn.....	62.36	82.2
			Sn, 4; Zn.....	63.77	80.7

## COEFFICIENTS OF EXPANSION OF LIQUID ALLOYS AND AMALGAMS

See also Tables 41–45; for definitions, v. p. 459.

TABLE 39.—CUBICAL EXPANSION OF LIQUID ALLOYS AND AMALGAMS

% composition	Approx. M. P., °C	$10^6 A^*$	Range, °C	Lit.
Bi, 50; Hg, 50.....	162.7	134	163 to 280	(19.1)
Bi, 67; Pb, 33.....		138	130	(138)
Bi, 57; Sn, 43.....		122	140	(138)
Bi, 70; Tl, 30.....		131	212–325	(102)
Cd, 90; Zn, 10.....		153	265	(138)
Hg, 80; Pb, 20.....	102	161	250 to 300	(19.1)
Hg, 66; Pb, 34.....	125	143	250 to 300	(19.1)
Hg, 40; Pb, 60.....	193	139	250 to 300	(19.1)
Hg, 25; Pb, 75.....	236	135	250 to 300	(19.1)

TABLE 39.—CUBICAL EXPANSION OF LIQUID ALLOYS AND AMALGAMS (Continued)

% composition	Approx. M. P., °C	10 <sup>6</sup> A *	Range, °C	Lit.
Hg, 77.3; Sn, 22.7.....	103.5	125	200 to 300	(19.1)
Hg, 63; Sn, 37.....	131	121	200 to 300	(19.1)
Hg, 46; Sn, 54.....	166	117	200 to 300	(19.1)
Hg, 29.8; Sn, 70.2.....	193	113	200 to 300	(19.1)
Hg; Sn... {	$d_4^t$ 13.3835 13.1807	$t^\circ$ 14.6 20.2		
		174.5 161.9	18 to 101 20 to 98	(91) (91)
Hg, 95.1; Tl, 4.9.....		179	20 to 30	(115)
Hg, 83.0; Tl, 17.0.....		175	20 to 30	(115)
Hg, 79.0; Tl, 21.0.....		161	20 to 30	(115)
Hg, 66.0; Tl, 34.0.....		140	20 to 30	(115)
Hg, 58.1; Tl, 42.9.....		157	20 to 30	(115)
Hg, 86; Zn, 14.....	152	184	300 to 350	(19.1)
Hg, 80; Zn, 20.....	200	181	300 to 350	(19.1)
Hg, 77; Zn, 23.....	217	153	300 to 350	(19.1)
Hg, 60.6; Zn, 39.4.....	288	146	300 to 350	(19.1)
Hg, 50.7; Zn, 49.3.....	316.5	ca. 200	330 to 360	(19.1)
K, 39; Na, 23†.....	4.5	286	10 to 100	(65)
Pb, 90; Sb, 10.....		123	250	(138)
Pb, 64; Sn, 36.....		127	262 to 356	(138)
Pb, 13; Sn, 87.....		112	249 to 355	(138)
Sn, 68; Cd, 32.....		123	175	(138)
Sn, 70; Tl, 30.....		118	200 to 300	(102)
Tl, 80; Sb, 20.....		227	200 to 225	(102)

\* If only one temperature is given,  $A = A_t$ ; if a temperature range,  $A = A_{t_1}^{t_2}$ .

† Equal atomic weights of each.

## VOLUME CHANGE ON FUSION AND SOLIDIFICATION, "MOLD SHRINKAGE"

Arrangement.—No definite arrangement is strictly followed in this section. Its scope and content will be seen by inspection.

TABLE 40.—FUSION OF PURE METALS ( $V_s$  = VOLUME OF SOLID AT M. P.)

Metal	Approx. M. P., °C	$100 \frac{\Delta V}{V_s}$	P. E.	Lit.
Ag.....	960	4.5	$\pm 0.5$	(45, 118)
Al, 99.....	658	6.7		(9, 43)
Al, 99.65.....		6.3		(45)
Au.....	1063	5.2		(45)
Bi.....	270	-3.3	$\pm 0.1$	(11, 45, 135, 138)
Cd.....	321	4.7	$\pm 0.1$	(45, 138)
Cs.....	26	2.5	$\pm 0.2$	(42, 64)
Cu.....	1083	4.1	$\pm 0.1$	(9, 10, 45)
K.....	62.5	2.5	$\pm 0.3$	(13, 45, 64, 65)
Li.....	185	1.5		(138)
Mg.....	650	4.2		(44)
Na.....	98	2.5	$\pm 0.1$	(6, 13, 14, 45, 65, 135)
Pb.....	325	3.4	$\pm 0.1$	(46)
Rb.....	38	2.5	$\pm 0.2$	(45, 64)
Sb.....	630	1.4		(135)
Sn.....	232	2.7	$\pm 0.1$	(11, 45, 135, 138)
	300	3.1		(135)
Tl.....		3.2		(45)
		4.3		(102)
Zn.....	420	6.5	$\pm 0.5$	(135)



TABLE 41.—SOLIDIFICATION OF PURE METALS (143)

% metal	Casting temp., °C	F. P., °C	$-100 \frac{\Delta l}{l}$		
			At F. P.	In solid state*	Total
Al, 99.2.....	800 to 850	683			1.78
Bi, 99.8.....	500	261		0.29	
Cu, 99.16....	1250	1060		1.40	1.42
Pb, 98.2.....	500 to 600	326	0.075	0.75	0.825
Sn, 99.8 to 100	500 to 550	225	0.01 to 0.15		0.44 to 0.55
Zn, 97.3.....	650 to 750	416	0.08	1.32	1.40

\* Final temperature is 15 to 20°C.

TABLE 42.—SOLIDIFICATION OF BI-SN (9, 10)

% Bi	A <sub>t</sub> for liquid	Range, °C	$-100 \frac{\Delta V}{V_{800^\circ}}$			
			800°C to F. P.	At F. P.	F. P. to 20°	800 to 20°C
100	0.00012	267.5 to 800	6.2	-3.01	1.32	4.51
90	0.00014	233 to 800	7.1			4.10
75	0.00014	185 to 800	7.6			7.17
58	0.00012	136.5 to 800	7.35	-1.12	1.36	7.58
40	0.00011	173 to 800	6.5			8.12
25	0.00011	199 to 800	5.95			8.32
15	0.00014	215 to 800	7.5			10.85
10	0.000135	220 to 800	7.4			13.4
0	0.000104	360 to 630	5.6	+2.7	1.64	9.99

TABLE 43.—SOLIDIFICATION OF CU-AL (9, 10)

% Cu	A <sub>t</sub> for liquid	Range, °C	$-100 \frac{\Delta V}{V_{1200^\circ}}$			
			1200°C to F. P.	At F. P.	F. P. to 20°C	Total
93	0.00014	1070 to 1200	1.73	4.25	5.08	11.06
85	0.00012	1035 to 1200	2.04	3.85	5.80	11.7
77.5	0.00013	950 to 1200	3.24	4.06	4.51	11.8
65	0.00012	725 to 1200	5.43			9.63
54	0.00013	585 to 1200	7.6			11.3
18	0.00013	543 to 1200	6.7			16.1
0	0.000125	657 to 1200	6.5	(5.8)	(4.3)	16.5

TABLE 44.—SOLIDIFICATION OF CU-SN (9, 10)

% Cu	A <sub>t</sub> for liquid	Range, °C	$-100 \frac{\Delta V}{V_{1200^\circ}}$			
			1200°C to F. P.	At F. P.	F. P. to 20°C	Total
100	0.00020	1084 to 1200	2.19	3.91	6.4	12.5
92	0.00015	1018 to 1200	2.57	5.06	5.52	12.85
82	0.00016	920 to 1200	4.25	4.25	4.79	13.28
71	0.00014	780 to 1200	5.53	3.61	4.68	13.83
62	0.00011	724 to 1200	5.58	3.28	5.88	14.76
35	0.00011	600 to 1200	6.18			13.35

TABLE 45.—SOLIDIFICATION OF CU-SB (9, 10)

% Cu	A <sub>t</sub> for liquid	Range, °C	$-100 \frac{\Delta V}{V_{1100^\circ}}$	
			1100°C to F. P.	1100 to 17°C
85	0.00016	940 to 1100	2.67	10.4
72	0.00012	646 to 1100	5.26	11.8
61	0.00011	670 to 1100	4.45	12.6
51.5	0.000115	665 to 1100	4.75	13.8
30	0.00012	550 to 1100	4.85	10.1
10	0.000115	580 to 1100	4.55	7.9
0	0.000104	630 to 1100	4.45	7.32

TABLE 46.—SPECIFIC VOLUME OF SB, 81.6; AL, 18.4 (118)

Temp., °C	$\frac{1}{d_4^t}$
700	0.240
800	0.241
900	0.241
1000	0.230
1025	0.221
1100	0.213
1135	0.211
1200	0.215

TABLE 47.—SOLIDIFICATION OF MISCELLANEOUS ALLOYS (143)

% composition	Casting temp., °C	Arrest temp., °C	$-100 \frac{\Delta l}{l}$ *
Pb, 80.82; Sn, 18.27.....	650	251	0.56
Pb, 29.1; Sn, 70.01.....	550	174	0.44
Pb, 18.39; Sn, 80.99.....	550	180	0.50
Pb, 80.61; Sb, 19.2.....	560 to 750	239	0.54
Pb, 85.2; Sb, 14.68.....	450 to 500	232	0.56
Sn, 50.83; Zn, 49.04.....	550	200	0.50
Sn, 85.4; Zn, 14.52.....	500	195	0.46
Sn, 95.15; Zn, 4.81.....	500	190	0.49

% composition	Casting temp., °C	T <sub>1</sub> °C† commencement of solidification		T <sub>E</sub> °C‡	100 $\frac{\Delta l}{l}$	T <sub>S</sub> °C§	$-100 \frac{\Delta l}{l}$ *
		T <sub>1</sub> °C	T <sub>2</sub> °C				
Cu, 83.45; Zn, 16.24.....	1000 to 1050	993		1000	0.3	973	2.17
Cu, 66.6; Zn, 32.9.....	950	902		904	0.03	870	1.98
Cu, 63.1; Zn, 36.24.....	870 to 950	874		928	0.03	877	1.97
Cu, 63.93; Zn, 35.25.....	900 to 1000	881		990	0.033	879	1.9
Cu, 94.7; Sn 5.08.....	1050	1035		1032	0.085	786	1.66
Cu, 89.65; Sn, 10.23.....	995 to 1150	996		980	0.122	706	1.44
Cu, 80.66; Sn, 19.08.....	900		760	835	0.01	752	1.52
Cu, 61.57; Ni, 16.1; Zn, 22.16	1100	1020		1068	0.045	917	2.025
Cu, 56.2; Ni, 20.4; Zn, 23.36	1065 to 1090	1060	1025	1049	0.039	924	2.05
Cu, 51.4; Ni, 26.22; Zn, 22.3	1150	1087	890	1080	0.027	949	2.03
Cu, 46.1; Ni, 35.8; Zn, 18.0	1170 to 1200	1085		1090	0.032	1010	1.935

% composition	Casting temp.	Arrest points, °C	T <sub>E</sub> °C‡	100 $\frac{\Delta l}{l}$	T <sub>S</sub> °C§	$-100 \frac{\Delta l}{l}$ *
Cu, 87.1; Sn, 2.68; Zn, 8.05; Pb, 2.28	1000°C	992, 895, 825, 685	973	0.025	840	1.76
Cu, 81.06; Sn, 17.5; Zn, 1.53..	950 to 1000°C	873, 775, 737, 603	854	.024	756	1.50
Cu, 88.75; Sn, 9.65; Zn, 1.6..	950 to 1020°C	977, 890, 824, 745	955	.058	726	1.47
Cu, 86.65; Sn, 9.84; Zn, 2.0; Pb, 1.44	1000°C	965, 840, 778, (848)	944	.075	750	1.47
Zn, 79.44; Sn, 14.48; Cu, 4.35; Pb, 1.66.....	500 to 500°C	379			374	1.02

TABLE 47.—SOLIDIFICATION OF MISCELLANEOUS ALLOYS (143).—  
(Continued)

% composition	Casting temp.	Arrest points, °C	T <sub>E</sub> , °C†	100 $\frac{\Delta l}{l}$	T <sub>S</sub> , °C§	-100 $\frac{\Delta l}{l}$ *
Zn, 51.22; Sn, 45.84; Cu, 1.9; Pb, 0.94.....	550 to 560°C	340			334	0.73
Pb, 78.89; Sb, 12.5; Cu, 8.45.....	600 to 650°C	250, 230			266	0.55
Sn, 19.8; Pb, 58.84; Sb, 21.4.....	600°C	263, 238			247	0.49
Sn, 85.42; Sb, 9.45; Cu, 5.1.....	500 to 550°C	225			225	0.51
Sn, 90.2; Sb, 8.0; Cu, 1.85.....	600 to 700°C	228			226	0.555
Sn, 70.83; Pb, 9.21; Sb, 15.1; Cu, 4.94.....	550 to 600°C	259, 187			228	0.425

\* The total linear shrinkages given above take place during cooling from the temperatures indicated in the table to atmospheric temperature (15 to 20°C).

† T<sub>L</sub>, T<sub>2</sub>, arrest points. ‡ T<sub>E</sub>, expansion begins. § T<sub>S</sub>, shrinkage begins.

TABLE 48.—SOLIDIFICATION OF CU-SN-X (BRONZES) (97)

% composition	Casting temp., °C	F. P., °C	Final temp., °C	Mold temp., °C	Expansion 100 $\frac{\Delta l}{l}$ *	Shrinkage -100 $\frac{\Delta l}{l}$
Cu, 92; Sn, 8.....	990	960	300	250	0.04	1.54
	970	960	500	200	.06	1.56
	980	960	500	200	.05	1.51
Cu, 92; Sn, 4; Al, 4.....	1170	1010	500	200	.05	1.88
	1080	1010	500	200	.04	1.86
Cu, 92; Sn, 7; Bi, 1.....	990	980	500	200	.065	1.41
	1030	980	500	250	.05	1.46
Cu, 92; Sn, 8; Bi, 0.5.....	1020	980	500	150	.05	1.47
	1000	980	500	200	.06	1.42
Cu, 90; Sn, 8; Co, 2.....	1000	970	400	250	.05	1.63
Cu, 90; Sn, 6; Co, 4.....	1080		400	300	.05	1.58
Cu, 90; Sn, 4; Co, 6.....	1040		400	300	.03	1.70
Cu, 90; Sn, 2; Co, 8.....	1030		300	150	.05	1.69
Cu, 90; Co, 10.....	1080		350	300	.05	
Cu, 92; Sn, 7; Fe, 1.....	990	990	500	250	.03	1.67
	1030	1010	500	250	.035	1.72
Cu, 92; Sn, 6; Fe, 2.....	1050	1010	500	200	.04	1.60
	1050	1010	500	250	.04	1.63
Cu, 92; Sn, 5; Mn, 3.....	1130	990	600	250	.03	1.54
	1100	990	550	200	.035	1.54
Cu, 92; Sn, 3; Mn, 5.....	1160	1010	600	200	.02	1.50
	1140	1000	500	250	.025	1.53
Cu, 92; Sn, 5; Ni, 3.....	1070	1040	480	250	.03	1.71
	1050	1040	500	200	.04	1.71
Cu, 90; Sn, 5; Ni, 5.....			250		.035	1.70
	1070	1040	550	200	.04	1.76
Cu, 92; Sn, 8; P, 2.....	1160	970	500	200	.015	1.43
	1080	960	500	200	.01	1.45
Cu, 92; Sn, 7; Pb, 1.....	1010	970	500	250	.06	1.58
	990	970	500	200	.05	1.50
Cu, 92; Sn, 6; Pb, 2.....	970	965	500	100	.05	1.48
	1050	980	500	250	.055	1.54
Cu, 92; Sn, 5; Pb, 3.....	985	980	500	300	.035	1.685
	990	980	500	200	.04	1.69
Cu, 92; Sn, 7; Sb, 1.....	1020	990	500	200	.04	1.58
	1000	985	500	150	.05	1.54
Cu, 92; Sn, 6; Sb, 2.....	1020	980	550	250	.05	1.53
	980	970	500	250	.035	1.47
Cu, 92; Sn, 5; Sb, 3.....	1010	970	530	200	.025	1.45
	995	970	500	100	.02	1.43
Cu, 92; Sn, 5; Si, 3.....	1020	970	500	250	.02	1.71
	1010	960	500	200	.01	1.75
Cu, 92; Sn, 8; W, 0.12...	1140	1080	600	200	.025	1.52
	1150	1080	500	100	.04	1.49
Cu, 92; Sn, 8; W, 0.15...	1160	1010	600	200	.035	1.52
	1090	1020	500	200	.02	1.50
Cu, 90; Sn, 8; Zn, 2.....	1080	970	500	200	.07	1.56
	990	960	500	300	.048	1.51
Cu, 90; Sn, 6; Zn, 4.....	1000	970	500	200	.04	1.57
	980	970	550	150	.05	1.64
Cu, 90; Sn, 4; Zn, 6.....	1080	1000	500	200	.05	1.59
	1010	995	500	350	.035	1.66

TABLE 48.—SOLIDIFICATION OF CU-SN-X (BRONZES) (97).—  
(Continued)

% composition	Casting temp., °C	F. P., °C	Final temp., °C	Mold temp., °C	Expansion 100 $\frac{\Delta l}{l}$ *	Shrinkage -100 $\frac{\Delta l}{l}$
Cu, 80; Sn, 10; Zn, 10...	1060	975	500	200	0.03	1.34
	1080	975	500	350	.025	1.33
Cu, 82; Sn, 10; Zn, 8....	1020	920	500	200	.025	1.35
	1040	910	500	400	.04	1.39
Cu, 84; Sn, 10; Zn, 6....	1060	930	500	200	.03	1.38
	1090	940	500	300	.03	1.43
Cu, 86; Sn, 10; Zn, 4....	1030	950	500	250	.03	1.47
	1020	940	500	250	.03	1.45
Cu, 88; Sn, 10; Zn, 2....	1020	960	500	300	.03	1.49
	990	960	500	250	.052	1.51
Cu, 80; Sn, 8; Zn, 12....	1040	940	500	250	.03	1.43
	1000	930	500	150	.04	1.46
Cu, 80; Sn, 6; Zn, 14....	1000	870	500	250	.04	1.47
	1040	890	500	250	.025	1.54

\* In all the above alloys a slight increase in length always occurred before the commencement of the shrinkage.

TABLE 49.—EFFECT OF MN CONTENT ON SHRINKAGE OF GRAY CAST IRON (28)

% Mn	-100 $\frac{\Delta l}{l}$ *	% Mn	-100 $\frac{\Delta l}{l}$ *
1.00	0.90	6.62	1.42
1.61	1.02	9.89	1.52
2.65	1.07	11.15	1.74
3.45	1.01	17.51	1.74
4.19	1.26	30.30	1.96
5.15	1.31		

\* Total shrinkage from F. P. to 20°C.

TABLE 50.—EFFECT OF MN CONTENT ON EXPANSION DURING  
SOLIDIFICATION OF GRAY CAST IRON (28)

% composition				100 $\frac{\Delta l}{l}$
C		Mn	Si	
Total	Graphite			
3.56	2.87	0.55	2.45	0.161
3.70	3.39	1.00	2.46	.219
3.63	3.16	1.61	2.35	.116
3.60	3.25	2.23	2.35	.152
3.60	3.33	2.65	2.39	.159
3.70	3.12	3.45	2.48	.162
3.80	2.94	4.19	2.44	.178
3.12	2.69	5.15	2.40	.155
3.40	2.65	5.83	2.34	.161
3.24	2.60	6.62	2.40	.190
3.85	2.15	8.35	2.38	.165
3.85	2.10	9.89	2.45	.257
3.95	1.98	10.30	2.41	.241
4.00	1.85	11.15	2.48	.188
4.25	1.14	17.57	2.54	.281
3.89		30.30	2.96	.097

TABLE 51.—EFFECT OF MN CONTENT ON EXPANSION DURING  
SOLIDIFICATION OF WHITE CAST IRON (28)

% composition			100 $\frac{\Delta l}{l}$
C	Mn	Si	
3.19	0.43	0.053	0.022
3.24	0.82		.032
3.28	1.48		.058
3.05	1.67	0.055	.068
3.09	2.37		.066
3.19	2.82		.049
3.12	3.50	0.050	.034



TABLE 51.—EFFECT OF MN CONTENT ON EXPANSION DURING SOLIDIFICATION OF WHITE CAST IRON (28).—(Continued)

% composition			$100 \frac{\Delta l}{l}$
C	Mn	Si	
3.14	4.42		0.019
3.19	5.25	0.061	.015
3.45	5.40	0.083	.039
3.43	6.30		.058
3.39	7.20	0.081	.082
3.36	9.00	0.068	.058
3.45	9.12		.068
3.50	10.40		.058
3.46	10.67	0.072	.078
3.50	12.35		.087
3.49	13.50		.068
3.65	13.70	0.085	.053
3.41	14.84		.024
3.80	16.00		.068
3.45	16.20	0.100	.058
3.76	17.05		.339
3.91	18.65		.008
3.81	19.65		.029
3.85	23.30	0.120	.097
3.95	30.50	0.173	.097
3.85	34.10	0.156	.097
3.93	38.55	0.155	.102

## CHANGES IN VOLUME DUE TO TEMPERING

TABLE 52.—CHANGES IN VOLUME OF ALLOYS DUE TO TEMPERING (101)

% composition	Heated to °C	Tempered at °C	$100 \frac{\Delta V}{V}$
Cu, 90.5; Al, 9.5.....	1000	400	-0.03
	1000	900	-0.08
	1000	1000	-0.16
Cu, 86.5; Al, 13.5.....	1000	650	-0.55
	1000	900	-0.42
	1000	1000	-0.58
Cu, 83.4; Al, 16.6.....	1000	400	-0.06
	1000	650	-0.15
	1000	1000	-0.15
Cu, 74.1; Al, 25.9.....	700	700	0.08
Cu, 74.9; Sn, 25.1.....	700	700	-0.10
Cu, 72.7; Sn, 28.1.....	700	700	-0.30
Cu, 71.9; Sn, 28.1.....	700	700	-0.22
	700	600	-0.27
	1000	700	0.46
	1000	750	0.46
	1000	800	0.47
Fe with 0.58 C.....	1000	900	0.47
	1000	1000	0.46
	1000	700	0.67
	1000	750	0.73
	1000	800	0.75
Fe with 0.70 C.....	1000	900	0.82
	1000	1000	0.85
	1000	650	0.17
	1000	700	0.23
	1000	750	0.96
Fe with 0.83 C.....	1000	800	0.99
	1000	900	1.10
	1000	1000	1.13

TABLE 52.—CHANGES IN VOLUME OF ALLOYS DUE TO TEMPERING (101).—(Continued)

% composition	Heated to °C	Tempered at °C	$100 \frac{\Delta V}{V}$
Zn, 80.3; Cu, 19.7.....	600	600	-0.08
Zn, 75.5; Cu, 24.5.....	600	600	-0.32
Zn, 74.5; Cu, 25.5.....	600	600	-0.40
Zn, 57.8; Cu, 42.2.....	800	750	0.24
Same (reheated).....	800	750	0.40
Zn, 47.4; Cu, 52.6.....	800	750	0.16

See also Table 12, p. 516.

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## MECHANICAL PROPERTIES OF IRON, Fe-Co, Fe-Ti, AND TITANIUM AND URANIUM STEELS

D. HANSON

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### PROPERTIES OF ELECTROLYTIC IRON

% composition	Treatment	E	BHN	10 × UTS	10 × YP	10 × PL	10 × El <sub>a</sub>	RA	Lit.
C, 0.029; Si, 0.004; S, 0.048; P, 0.0037; Mn, 0.0	Dp A 600° A 800° A 950°			800 440 372 299 296	780 364 312 178 187		30 188 280 427 373		(1)
C, 0.031; Mn, 0.02; (Si, S, P), Tr.; Cu, 0.0	A 1000°		77 77	295 295	143 137	43 68			(5) (5)
O, 0.08; P, 0.007*	N <sub>a</sub> †	21 000 20 700	66 69	239 255	131 146	39 68	500 70	80 10	(8) (8)
O, 0.23; P, 0.007*.....	N <sub>v</sub> †	20 700		295	109	58	20	4	(8)

\* Other elements absent or trace.

† Previous treatment: M<sub>1</sub> R<sub>h</sub> 80 % N.

### YOUNG'S MODULUS (TENSION) OF Fe-Co (4)

% Co	E/10	% Co	E/10	% composition of components of alloy		
				Fe	Co	
0	2129	40	2109	C	0.09	0.24
5	2101	70	1873	Si	.11	0.14
10	2071	80	1737	Mn	.31	Ni, 1.1
15	2132	90	1973	P	.03	Fe, 1.4
20	2161	100	2079	S	.026	
30	2175			Cu	.288	

### HARDNESS OF Fe-Ti (6)

% Ti	BHN*	% Ti	BHN*
0.00	96	11.73	327
0.75	144	14.51	350
3.33	214	15.56	360
4.50	242	19.42	405
7.30	312	19.90	472
8.92	373	21.50	484

\* Ball diam. = 5 mm; 500 kg applied ½ min.

### TITANIUM AND URANIUM STEELS

#### Fe-Cr-U-C, Cr-U Steel (7)

Composition, hundredths %					Treatment		UTS	YP	El <sub>a</sub>	RA
Cr	U	C	Mn	Si						
78	17	36	53	25	835° Q <sub>o</sub> 300°/30 C <sub>a</sub> .....		170	143.4	9.0	37.2
81	31	30	57	57	850° Q <sub>w</sub> 250°/2 h C <sub>a</sub> .....		142.5	98.5	8.0	36.6
					875° Q <sub>w</sub> 250°/2 h C <sub>a</sub> .....		157.5	107	10.5	42.2
					875° Q <sub>w</sub> 350°/2 h C <sub>a</sub> .....		130.6	113.5	14	57.6
					900° Q <sub>w</sub> 250°/2 h C <sub>a</sub> .....		150.5	111.8	11	45.2

### Fe-Ni-Cr-U-C, Ni-Cr-U Steel (7)

% composition	Treatment	UTS	YP	El <sub>a</sub>	RA
Fe; Ni, 1.63; Cr, 0.61; U, 0.20; C, 0.36; Mn, 0.78; Si, 0.47	825° Q <sub>o</sub>	175	150	11	38.2
	850° Q <sub>o</sub>	175	140	13	47.2
	770°	150	117.3	13	50.6
	775° Q <sub>w</sub> 350°/2 h C <sub>a</sub> .....	134	106.3	13	60.2

### Fe-Ni-U-C, Ni-U Steel (7)

Composition, hundredths %					Treatment		UTS	YP	El <sub>a</sub>	RA
Ni	U	C	Mn	Si						
307	26	83	74	58	775° Q <sub>o</sub> 300°/2 h C <sub>z</sub> .....		172	148	2.5	4.7
313	36	25	46	20	775° Q <sub>w</sub> 250°/2 h C <sub>a</sub> .....		134	121	11.5	43.4
315	22	43	54	60	790° Q <sub>o</sub>		191	158	12	43.3
					775° Q <sub>o</sub>		191	162	13	44.8
					775° Q <sub>o</sub>		186	148	12	47
315	40	57	62	58	790° Q <sub>o</sub> 250°/2 h C <sub>z</sub> .....		209	183	8.5	32.6
322	32	30	48	64	780° Q <sub>o</sub> 250°/2 h C <sub>a</sub> .....		183	159	9.5	34.1
					780° Q <sub>o</sub> 250°/2 h C <sub>z</sub> .....		181	161	9.0	34.1
367	36	45	72	68	775° Q <sub>o</sub>		197	187	8.5	32.5
					775° Q <sub>o</sub>		206	170	9.0	31.1
					800° Q <sub>o</sub>		209	175	9.0	30.8

### Fe-Ti-C, Ti Steels (3)

Class	Composition, thousandths %						Trt	BHN	UTS	YP	El	RA
	Ti	C	Mn	P	S	Si						
Low carbon Ti steel	415	122	180	18	15	47	F.....	99	40.7	33.9	20	68
							Q <sub>w</sub> *.....	114	51.0	47.2	10	59
	879	106	140	20	15	163	F.....	105	45.2	37.6	19	68
							Q <sub>w</sub> *.....	153	58.0	51.2	7.5	64
	1398	137	170	20	7	105	F.....	101	48.2	36.1	19	62
							Q <sub>w</sub> *.....	126	61.3	52.1	8	58
	2570	135	310	10	17	140	F.....	90	45.2	34.6	17.5	68
							Q <sub>w</sub> *.....	143	66.2	45.2	9.5	52
	325	760	230	15	15	292	F.....	207	94.1	54.9	7.5	19
							Q <sub>w</sub> *.....	455				
High carbon Ti steel	640	695	240	25	24	256	F.....	207	94.1	52.6	9	28
							Q <sub>w</sub> *.....	412				
	720	624	230	21	11	350	F.....	212	87.7	53.3	10	37
							Q <sub>w</sub> *.....	387				
	2575	611	270	15	25	411	F.....	212	90.4	58.8	10.5	35
							Q <sub>w</sub> *.....	340	120.3	78.5	2	4
	4630	635	315	13	18	346	F.....	212	89.8	57.8	9.5	34
							Q <sub>w</sub> *.....	366				
	8710	650	450	16	11	163	F.....	248	117.5	62.5	8.5	30
							Q <sub>w</sub> *.....	477	132.5	80.3	0.0	0

\* Quenched from 850°C in cold water.



Fe-U-C, U Steel (7\*)

Composition, hundredths %					Treatment	UTS	YP	El <sub>a</sub>	RA
U	C	Mn	Si	V					
28	25	80	39	Tr.	850° Q <sub>w</sub> 300°/2 h C <sub>a</sub> .....	130.4	114	13.5	54.4
45	28	66	47	0	{ 850° Q <sub>w</sub> 300°/2 h C <sub>a</sub> ..... 850° Q <sub>w</sub> 350°/2 h C <sub>a</sub> .....	120 98.3	90.2 84.3	11 14.5	53 55.5
50	17	25	30	Tr.	{ 880° Q <sub>w</sub> 250°/1 h C <sub>a</sub> ..... 880° Q <sub>w</sub> 400°/1 h C <sub>a</sub> .....	54.2 56.1	34.0 42.1	30 32	61.8 66.4
85	21	65	36	Tr.	{ A..... 850° Q <sub>w</sub> } 300°/2 h C <sub>a</sub> ..... 875° Q <sub>w</sub> } 900° Q <sub>w</sub> 400°/2 h C <sub>a</sub> .....	56.1 121.3 124.4 94.2	44 109.5 112 83.2	30.5 12 10.5 16	61 47.2 47.2 53.6
220	25	65	30	Tr.	{ 925° Q <sub>w</sub> 250°/2 h C <sub>a</sub> ..... 900° Q <sub>w</sub> ..... 900° Q <sub>w</sub> 250°/2 h C <sub>a</sub> .....	144.4 160.6 144.9	124 145 125	9 3.0 8	35.4 7.3 31.5
2	46	33	41		850° Q <sub>w</sub> 400°/1 h C <sub>a</sub> .....	96.8	67.1	16.5	37.3
2	51	24	18		{ 875° } Q <sub>w</sub> 400°/1 h C <sub>a</sub> ..... 825° }	119.6 98.2	67.1 77.2	9 12	16 28.5
12	46	34	63	Tr.	{ 850° Q <sub>w</sub> 400°/1 h C <sub>a</sub> ..... 900° Q <sub>w</sub> 300°/2 h C <sub>a</sub> ..... 825° Q <sub>w</sub> 400°/1 h C <sub>a</sub> .....	94.2 89.1 86.1	71.2 71.2 71.2	14 23 21	39.5 53.7 54.7
13	36	23	10	Tr.	875° Q <sub>w</sub> 400°/2 h C <sub>f</sub> .....	76.1	59.1	22.5	58.1
13	55	21	20	4	{ 875° } Q <sub>w</sub> 400°/1 h C <sub>a</sub> ..... 880° } 825° } 825° }	104.0 104.7 98.3 98.3	80.3 75.1 78.1 76.2	14 11.5 17.5 18	35.1 32.5 51.7 49.5
22	32	66	23 (2)		843° Q <sub>w</sub> T <sub>p</sub> { 204°..... 260°..... 316°..... 371°.....	161.7 150.0 136.2 114.1	148 132.6 126.7 118.7	11.0 12.0 13.5 15.5	43.3 51.0 52.0 59.3
29	54	61	28 (2)		802° Q <sub>w</sub> T <sub>p</sub> { 260°..... 316°..... 371°.....	197 175 144.4	181 160 131.5	8 10 11	34.0 40.3 43.3

Fe-U-C, U Steel (7\*).—(Continued)

Composition, hundredths %					Treatment	UTS	YP	El <sub>a</sub>	RA
U	C	Mn	Si	V					
31	45	68	33 (2)		816° Q <sub>w</sub> T <sub>p</sub> { 260°..... 316°..... 371°.....	176.0 153 132.3	158.3 141 120.5	10.5 12.5 14.0	42.8 48.1 54.2
152	43	55	56	Tr.	815° Q <sub>o</sub> 300°/2 h C <sub>a</sub> .....	66.1	45.0	11.5	44.6
312	47	80	80	Tr.	815° Q <sub>o</sub> 400°/2 h C <sub>a</sub> .....	130.2	107	10.5	34.7
6	63	34	64		875° Q <sub>o</sub> 500°/2 h C.....	118	83.2	14	40.1
53	72	54	75		{ 790° Q <sub>o</sub> 300°/2 h C <sub>a</sub> ..... 300°/2 h C <sub>f</sub> ..... 300°/2 h C <sub>f</sub> ..... 350°/2 h C <sub>z</sub> ..... 870°-790° Q <sub>o</sub> { 300°/2 h C <sub>f</sub> ..... 350°/2 h C <sub>z</sub> ..... 850°-775° Q <sub>o</sub> 350°/2 h C <sub>a</sub> ..... 870°-790° Q <sub>o</sub> 400°/1 h C <sub>a</sub> ..... 850°-770° Q <sub>o</sub> { 400° } 2 h C <sub>a</sub> ..... 450° } 870°-790° Q <sub>o</sub> 500°/1 h C <sub>a</sub> .....	233 205 202 167 154.5 173 157.5 170 125.1 132.2	197 184 181 149.5 128 157.5 126 109.5 116.5	1.5 14 14.5 17.5 10 7 10 12.5 12.5	0.7 13 19.2 20.6 31.1 24.7 31.5 33.1 30.1
190	63	77	75	Tr.	{ 875° } 300°/2 h C <sub>a</sub> ..... 900° } 800° } 850° } 400°/2 h C <sub>a</sub> ..... 875° } 900° }	189 197 96.2 130.7 130.7 132.3	174.8 148 69.1 117.4 92.3 120.5	7 6 8.5 10 11 9.5	22.3 18.1 21.6 30.8 32.5 30.2

\* Except where noted.

## LITERATURE

(For a key to the periodicals see end of volume)

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## NI AND ITS ALLOYS WITH C, CR, CU, FE, AND MN

P. D. MERICA

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<sup>1</sup> Furnished by T. H. Wickenden.

## MECHANICAL AND ELASTIC PROPERTIES

TABLE 1.—Ni

Standard 99% commercially pure "malleable" Ni\* containing Co, 0.40; Fe, 0.40; Cu, 0.15; Mn, 0.15; C, 0.10; Si, 0.10 (5, 8, 19, 29); *v. also* references under separate items.

Shape	Trt†	UTS	YP‡	PL§	El <sub>a</sub>	RA
Bars.....	R <sub>h</sub>	46-56	18-28	11-21	40-60††	50-70
	RA	42-53	14-25	11-18	40-60††	50-70
	R <sub>c</sub> **	53-120	25-105	18-70	40-1††	50-5
Sheet or strip.....	RA	42-53	14-25	11-18	30-45†	
	R <sub>c</sub> **	53-120	25-105	18-70	30-1†	
Wire.....	DA	42-53	14-25	11-18	20-40†	
	D <sub>c</sub> **	53-120	25-105	18-70	20-1†	
Castings.....	G <sub>s</sub>	35-49	14-21		20-35††	20-50

$d_4^{20} = 8.80-8.90$  (11, 13, 22).

Compressibility same as pure Ni (*v. vol.* III).

Trt	Load		ScH universal hammer	RHN	Elastic constants	
	BHN, 10 mm ball				10 <sup>3</sup> kg/mm <sup>2</sup>	Lit.
A.....	90-110	70-90	8-12	35-50	E	20.4-21.8 (12, 15, 17, 21, 22)
R <sub>c</sub> .....	110-300	90-300	12-50	50-110	G	7.2-7.7 (20)
G <sub>s</sub> .....	90-110	70-90	8-12		λ	0.33 (4)

\* Indications of a few tests are that data apply equally well to pure Ni, but data on pure Ni are too scanty to be useful. For specific gravity *v. p.* 456; compressibility *v. vol.* III; viscosity *v. vol.* III; surface tension *v. vol.* III.

† Depends on gage of metal, larger for heavier gages.

‡ By drop of beam or at  $\Delta l = \frac{1}{2}\%$   $l_0$ .

§ By extensometer.

|| May be regarded as the normal or standard state.

¶ See p. 392.

\*\* Ranges are large and depend on amount of cold work which varies from 5-95% reduction of section.

†† Diam. = 0.505 in.

TABLE 2.—Ni-Cr-Fe AND Ni-Fe-Cr, "CHROMEL," ETC. (19)

% Ni	% Cr	% Fe	Ind. No.	Trt	UTS	YP	El <sub>a</sub>	RA	BHN	$d_4^{20}$
82.5	15	1*	366	R <sub>h</sub>	74-88	42-56	25-45	50-65	175-210	8.30-8.50
77.5	20	1*	367	R <sub>h</sub>	77-91	49-63	25-40	50-65	180-220	
61.0	12	25†	368	R <sub>h</sub>	63-77	35-49	25-45	50-70	180-200	8.10-8.20
				G <sub>s</sub>	35-49	28-42	2-10		130-180	

\* Alloy contains also Mn, 1; C, 0.4; Si, 0.1.

† Alloy contains also Mn, 1; C, 0.5; Si, 0.5.

TABLE 3.—Ni-Cu-X

No satisfactory systematic data exist on the mechanical properties of the Ni-Cu series. The available data on certain well known commercial alloys are tabulated below.

There exist some data on Ni-Cu which indicate: (1)  $E$  is a linear function of % Cu. (2) Hardness is a maximum between 35 and 50% Cu, its value at the maximum being a little greater than that of pure Ni.

Ni, 68.4; Cu, 29.0; Fe, 2.0; Mn, 0.3; C, 0.2; Si, 0.1 "Monel metal" (7, 19)

Shape	Trt†	UTS	YP‡	PL§	El <sub>a</sub>	RA
Bars.....	R <sub>h</sub>	60-67	25-32	18-28	35-50††	45-65
	RA	46-53	18-28	14-21	35-50††	
	R <sub>c</sub> **	53-120	28-105	21-70	35-1††	45-50
Sheet or strip.....	RA	46-53	18-28	14-21	30-45†	
	R <sub>c</sub> **	53-120	28-105	21-70	30-1†	
Wire.....	DA	46-53	18-28	14-21	20-40†	
	D <sub>c</sub> **	53-120	28-105	21-70	20-1†	
Castings.....	G <sub>s</sub>	46-56	21-28		25-35††	

\*††§||\*\*†† For meanings *v.* footnotes to Table 1.

$d_4^{20} = 8.80-8.90$ .

UCS: Flattens, does not fracture.

YP<sub>C</sub> = 42-49 ( $\Delta l = -\frac{1}{2}\%$   $l_0$ ).

PL<sub>C</sub> = 25-32.

Trt	BHN, 10 mm ball		ScH universal hammer	RHN
	Load			
A.....	110-130	90-110	15-20	65-75
R <sub>h</sub> .....	140-160	110-130	22-28	75-85
R <sub>c</sub> .....	130-300	110-300	20-55	90-110
G <sub>s</sub> .....	110-130	90-110	15-20	60-70

$10^{-3} E = 16.8-18.3$ .

$10^{-3} G = 6.3-7.0$ .

USS (to punch sheet or shear rod) = 35-46.

TMR = 39-46.

PL<sub>S</sub> = 14-21.

IS { Standard Izod: Specimens merely bend over.

Standard Charpy: Specimens fracture; IS = 14-28 kg-m.

Twist:  $\pi \times$  diam.  $\times$  no. of turns = 2.5-3.0 in. (for hot rolled alloy).

Ni, 55; Cu, 43.9; Mn, 1.00; C, 0.10 "Constantan" (7, 19)

Trt	UTS	YP	El <sub>a</sub>	RA	BHN, 10 mm ball		ScH	RHN
					3000 kg	500 kg		
A.....	42-49	14-21	40-60	50-70	100-120	80-100	12-16	55-65
R <sub>c</sub> .....	49-99	21-88	40-1	50-5	120-300	120-300	16-50	

$d_4^{20} = 8.85 \pm 0.05$ .  $10^{-3} E = 14.8-16.2$ .

TABLE 4.—Cu-Ni, Cu-Ni-Zn, AND Cu-Zn-Ni\* (Cupro-nickel, Nickel-silver, Ambrac) (2)

% composition		M. P., °C	Ind. No	Condition								$d_4^{20}$	$\rho_{20}$
Ni	Zn			Hard				Soft					
				UTS	YP†	El <sub>a</sub>	BHN§	UTS	YP†	El <sub>a</sub>	BHN§		
15	¶	1170†	446	49		3		32		30		8.95	21.1
20		1190†	446	60		2		35		30			
25		1220†	446					37	13	38			
20	5**	1150	136	60	53	5	160	35	15	35	70	8.84	28.6
18	17	1110†	988	67	2	158	41	33	77			8.75	30.8
30	5	1220	135	74	67	2	190	46	20	28	85		
25	20	1130†	990	77	4	208	51	30		89		8.72	43.1
30	23	1140†	991	91	2		51	35				8.74	48.2
10	25	1010†	985	63		3		35		45		8.68	
15	21	1080†	987	63		5		35		40			
15	28	1030†	987	67		2		39		35			
18	27	1055†	988	77		1		42		40		8.68	30.9

\* For annealing ranges, *v.* Table 14.

† (28).

‡ Stress at which  $\Delta l = \frac{1}{2}\%$   $l_0$ .

§ 10 mm, 500 kg.

|| Electrical resistivity, microhm-cm.

¶  $E = 8.4 \times 10^3$  kg/mm<sup>2</sup>.

\*\*  $E = 13.4 \times 10^3$  kg/mm<sup>2</sup>.

TABLE 5.—TENSILE PROPERTIES AND HARDNESS OF Ni-Fe ALLOYS (9, 25) *v. also* Table 12

These alloys made out of 99.97% pure electrolytic Fe and electrolytic Ni. Analyses showed: C well under 0.01%, S, Si, P and Mn negligible.

A charge of electrolytic Fe was melted into an ingot and forged under same conditions employed in preparation of alloys. Analysis of this gave: C, 0.047; Mn, 0.0; Si, 0.062; P, 0.016; S, 0.005.

All except last three compositions were annealed at 900°C.

% Ni	UTS	YP	El <sub>a</sub>	RA	ScH
0.25	35.4	26.7	35.0	69.7	14.5
0.50	39.0	28.5	36.5	70.2	14
1.00	42.1	30.8	33.7	68.8	14
2.00	45.3	34.3	34.2	65.4	14
3.00	49.7	38.9	27.5	67.6	14.5
4.00	49.3	36.6	28.4	66.7	14



TABLE 5.—TENSILE PROPERTIES AND HARDNESS OF Ni-Fe ALLOYS (9, 25) *v. also* Table 12.—(Continued)

% Ni	UTS	YP	EL <sub>a</sub>	RA	ScH
5.00	51.5	41.0	31.4	68.1	15.5
6.00	52.9	39.7	29.5	64.2	
7.00	51.3	40.9	26.7	58.5	16
8.00	55.2	44.5	30.2	64.4	16
9.00	63.2	50.7	25.1	60.2	17
10.0	62.8	50.5	22.3	59.1	18
10.5	62.9	48.6	24.2	57.2	20
11.0	85.6	69.7	11.6	34.6	21
12.0	85.6	68.7	14.5	35.8	25
13.0	113.4	90.0	6.8	18.2	31.5
15.0	107.8	88.8	10.5	35.8	34
18.0	127.7	96.8	10.0	34.4	34
19.0	127.0	81.7	10.7	38.7	31
20.0	87.8	78.0	21.5	62.5	34.5
21.0	136.2	86.2	4.0	4.2	31
25	73.3	39.6	45.0	68.3	21
45	57.6	38.4	32.5	65.0	17
50	76.3	53.2	26.5	63.7	

TABLE 6.—COMPRESSION TESTS ON Ni-Fe ALLOYS\* (18)

% Ni	% C	% Mn	% Si	EL <sub>C</sub>	ε†
0.27	0.19	0.79	0.31	35	50
0.51	.14	.75	.20	35	50
0.95	.13	.72	.23	32	49
1.92	.14	.72	.21	43	47
3.82	.19	.65	.20	44	41
5.81	.18	.65	.31	63	37
7.65	.17	.68	.28	63	33
9.51	.16	.86	.20	110	3
11.39	.18	.93	.22	158	1
15.48	.23	.93	.24	126	1
19.64	.19	.93	.27	126	3
24.51	.16	1.00	.30	79	16
29.07	.14	0.86	.38	38	41

\* Specimens 1 in. × 0.798 in. diam. (forged, unannealed).

† ε = -100  $\frac{\Delta l}{l_0}$  for 158 kg/mm<sup>2</sup> load.

TABLE 7.—ELASTIC PROPERTIES OF Ni-Fe AND Ni-Fe-Cr ALLOYS (10, 17)

% Ni	10 <sup>-3</sup> E	% Ni	10 <sup>-3</sup> E	% Ni	10 <sup>-3</sup> E	% Ni	% Cr	10 <sup>-3</sup> E
5.0	21.7	27.9	18.1	39.4	15.1	12.2	1	19.0
15.0	19.1	30.4	16.0	44.3	16.3	16.2	2.5	19.6
19.0	17.7	31.4	15.5	70.0	19.8	16.8	1	18.3
24.1*	19.3	34.6	15.4	100.0	21.6	34.8	1.5	15.5
24.1†	17.4	35.2	14.9			35.7	1.7	15.7
26.2	18.5	37.2	14.6			36.4	0.9	15.7

\* Non-magnetic.

† Magnetic, transformation probably incomplete.

TABLE 8.—DENSITY (gm/cm<sup>3</sup>) OF Ni-Fe ALLOYS\* (7)

% Ni	0	10	20	30	40	50	60	70	80	90	100
100 d	787.5	789	802	806	763?	805	829	839	852	860	886

\* Fairly pure Ni-Fe.

TABLE 9.—TENSILE, HARDNESS AND IMPACT TESTS ON Ni-STEELS (Ni &lt; 6%)\*

Treatment	UTS	E = EL† P = PL Y = YP	EL <sub>a</sub>	RA	BHN	IS† kg-m per cm <sup>2</sup>
Ni, 1.76; C, 0.26; Mn, 0.90; Si, 0.18; S, 0.02; P, 0.04 (14)						
G <sub>a</sub> W 800°/4 h C <sub>a</sub> 1 h	67.5	39.4 E	15§	14		5.1 <sub>v</sub>
Same, T <sub>p</sub> 700°/1 h C 6 h	61.0	36.9 E	21	22.5		7.5 <sub>v</sub>
G <sub>a</sub> W 800°/4 h C <sub>f</sub> 18 h	64.8	36.6 E	28.5	39.8		8.2 <sub>v</sub>
Same, T <sub>p</sub> 700°/1 h C 6 h	64.5	37.0 E	33	52.8		33 <sub>v</sub>

TABLE 9.—TENSILE, HARDNESS AND IMPACT TESTS ON Ni-STEELS (Ni &lt; 6%)\*—(Continued)

Treatment	UTS	E = EL† P = PL Y = YP	EL <sub>a</sub>	RA	BHN	IS† kg-m
Ni, 2.73; C, 0.37; Mn, 0.54; Si, 0.18; S, 0.02; P, 0.015; Cu, 0.042 (23)¶						
G <sub>a</sub> A** tangential	56.9	34.3 Y	19.4	29.0		1.87 <sub>v</sub>
G <sub>a</sub> A** longitudinal	56.8	34.6 Y	21.0	23.9		2.34 <sub>v</sub>
G <sub>a</sub> F <sub>m</sub> tangential	66.2	38.7 Y	21.8	44.7		2.90 <sub>v</sub>
G <sub>a</sub> F <sub>m</sub> longitudinal	66.3	38.2 Y	23.6	49.8		2.67 <sub>v</sub>
G <sub>a</sub> F Trt†† tangential	62.4	45.2 Y	25.5	64.6		4.36 <sub>v</sub>
G <sub>a</sub> F Trt†† longitudinal	64.3	45.5 Y	26.2	65.7		3.51 <sub>v</sub>
G <sub>a</sub> Trt†† tangential	59.2	41.1 Y	24.2	48.9		2.98 <sub>v</sub>
G <sub>a</sub> Trt†† longitudinal	64.3	46.9 Y	24.7	53.2		2.74 <sub>v</sub>

Ni, 2.30; C, 0.44; Mn, 0.43; Si, 0.48; S, 0.016; P, 0.017; Cu, 0.062 (23)¶

G <sub>a</sub> A** tangential	65.3	39.2 Y	12.1	14.2		0.69 <sub>v</sub>
G <sub>a</sub> A** longitudinal	65.7	39.7 Y	12.0	13.2		0.74 <sub>v</sub>

Ni, 3.59; C, 0.20; Mn, 0.69; Si, 0.18; P, 0.007; S, 0.013 (27)

A (0.505 in. diam.)	55.5	39 E	31.0	64.7	143	10.42 <sub>u</sub>
843° Q <sub>o</sub> T <sub>p</sub> (½ in. diam.)	100°	138	112 E	12.5	41.5	6.78 <sub>u</sub>
	205°	136	102 E	11.0	45.6	6.42 <sub>u</sub>
	427°	105	88 E	15.5	68	9.74 <sub>u</sub>
	538°	81	67 E	20.3	73	11.46 <sub>u</sub>

Ni, 3.35-3.70; C, 0.30-0.37; Mn, 0.57-0.70; P, 0.008-0.04; S, 0.020-0.045 (3, 6, 24, 29)

A (½-1.5 in. diam.)	55 - 69.5	39 - 42††	31 - 26.5	56-55	160-170	
788-860° Q <sub>w</sub> T <sub>p</sub>	650°	76 - 81.5	59 - 67.5	26.5-22	69-60	200-225
	600°	84 - 91	71 - 77	23.5-20	67-60	226-248
	500°	96 - 112.5	85 - 99	20 - 17	61-57	290-302
	400°	118 - 134	105 - 119	15 - 12	57-50	340-360
	300°	146 - 156	129 - 135	13 - 12	54-48	370-444

Ni, 3.70; C, 0.36; Mn, 0.73; Si, 0.15; P, 0.007; S, 0.011 (27)

843° Q <sub>o</sub> T <sub>p</sub> 427°	130	120	14.5	61.2	342	11.1 <sub>u</sub>
	155	141	12.0	57.5	429	4.6 <sub>u</sub>

Ni, 4.6-5.3; C, 0.12-0.17; Mn, 0.30-0.62; P, 0.008-0.046; S, 0.018-0.045 (92)

A	50.5- 59	35 - 41††	34 - 25.5	60-48	149-170	10.7 <sub>u</sub> 10.5 <sub>v</sub>
760-900° Q <sub>o</sub> T <sub>p</sub>	650°	62 - 77	41 - 66	34 - 22.5	71-66	172-217
	600°	64 - 82	43.5- 72	32.5-22	70-62	180-230
	500°	74.5- 93	55 - 81	28 - 18	70-58	215-260
	400°	91 - 115	72 - 93	23 - 14	68-47	257-318
	100°	121 - 135	96 - 112	15 - 11.5	55-38	330-365
						3.6 <sub>u</sub> 4.5 <sub>v</sub>
						ScH

Ni, 2.31-3.75; C, 0.15-0.20; Mn, 0.34-0.60; P, 0.006-0.023; S, 0.025-0.033 (3, 29)

A (1-1.5 in. diam.)	50.5- 56	31.5- 48††	35 - 32	65-52	126-145	22-26
802-848° Q <sub>o</sub> T <sub>p</sub>	650°	53 - 57.5	33 - 42.5	33 - 28	76-67	150-178
	600°	55 - 67	37 - 47	32 - 26	73-68	170-200
	500°	65 - 86	48 - 66	27 - 22	68-62	187-277
	400°	79.5- 97	60 - 82	22.5-15	65-53	190-325
	300°	83 - 115	60.5- 93	22 - 13	59-48	192-358

Ni, 3.16-3.65; C, 0.35-0.39; Mn, 0.48-0.65; Si, 0.10-0.22; P, 0.009-0.041; S, 0.020-0.036 (3, 6, 28, 29)

A (1-1.5 in. diam.)	67 - 70	42- 43.5††	28 - 25	56-48	183-200	26-35
773-860° Q <sub>o</sub> T <sub>p</sub>	650°	73 - 81	43- 68	28 - 22	67-62	217-230
	600°	74.5- 88	51- 72	28 - 21	65-62	229-244
	500°	86.5-101	76- 88	20 - 17	60-54	265-296
	400°	109 - 134	91-112	16 - 12.5	50-47	325-349
	300°	135 - 165	112-151	13 - 11	45-43	385-420

\* The average effect of Ni up to 8 % upon an Fe-C alloy in the fully annealed condition is as follows: 0.01 % Ni increases EL by 28 g/mm<sup>2</sup>, UTS by 29.5 g/mm<sup>2</sup>, RA by 0.005 %, decreases EL by 0.010 % (1).

† Some data not clear as to whether PL, EL, or YP is measured.

‡ Subscripts to values of IS: u = Izod machine, v = Charpy machine.

§ Specimens 50 mm × 13.8 mm diam.

|| Specimens 30 mm sq. × 160 mm long, notch 2 mm radius.

¶ Taken from ring-casting 71.5 in. long by 10.9 in. diam.

\*\* A = A 950°/4 h C<sub>a</sub>, W 600°/6 h.†† Trt = 800°/1 h Q<sub>w</sub> T<sub>p</sub> 675°.

‡‡ Data not clear as to method, lower figure generally reported as EL, higher as YP.

TABLE 10.—TORSION TESTS ON NI-STEELS (27)

Treatment (in 1 in. diam.)	UTS	EL	EL <sub>a</sub> *	RA	TMR	ELs	T <sub>w</sub> (°/cm)	TMR UTS	ELs EL
Ni, 3.48; C, 0.19; Mn, 0.70; Si, 0.10; P, 0.009; S, 0.019									
843° Q <sub>o</sub> Tp	85.7	58.7	17.0	56.7	81.7	28.6	35.9	97	48
205°	90.3	60.8	16.5	47.4	88.9	28.6	28.7		
843° Q <sub>o</sub> Tp	92.9	65.3	16.5	49.1	89.1	28.6	32.0	98	45
150°	88.2	62.5	17.0	53.5	88.6	28.6	42.8		
A.....	53.2	34.4	23.5	67.0	51.9	21.4	64.3	99	67
	52.2	35.1	23.0	65.1	53.3	25.2	51.9		
K (1/32)	83.1	63.2	18.0	63.7	76.7	34.8	7.9	96	55
815° Q <sub>o</sub>	83.3	63.2	17.5	63.5	79.4	34.0	8.5		
Tp 315°									
Ni, 3.66; C, 0.30; Mn, 0.70; Si, 0.18; P, 0.011; S, 0.010									
845° Q <sub>o</sub> Tp	80.1	61.1	19.5	66.0	69.9	39.4	54.5	90	69
650°	77.3	60.4	21.0	67.5	69.8	43.0	63.4		
845° Q <sub>o</sub> Tp	92.8	71.7	16.5	59.2	80.8	45.9	79.6	87	64
425°	93.3	72.7	18.0	58.2	81.2	46.5	76.8		
A.....	65.4	36.2	18.5	50.7	60.8	17.9	39.4	93	47
A†.....	64.5	35.5	15.0	52.7	58.9	16.2	39.6		

\* Diam. = 0.505 in.

† Broke near end.

TABLE 11.—EFFECT OF HEAT TREATMENT ON IMPACT STRENGTH OF NI-STEELS (3)

Composition A = Ni, 2.9; C, 0.17; Mn, 0.34; Si, 0.05; P, 0.023; S, 0.033.

Composition B = Ni, 3.65; C, 0.37; Mn, 0.65; Si, 0.17; P, 0.030; S, 0.020.

Composition C = Ni, 6.00; C, 0.17; Mn, 0.34; Si, 0.39; P, 0.014; S, 0.014.

Treatment	Composition A		Composition B		Composition C	
	IS	IS	IS	IS	IS	IS
	Izod	Charpy	Izod	Charpy	Izod	Charpy
N 860°.....	12.3	14.7	5.0	4.5	10.7	10.5
860° Q <sub>w</sub> .....	4.0	3.9	0.6	0.8	4.3	4.6
300°	4.8	5.8	0.6	1.0	4.6	4.5
400°	7.5	7.2	1.1	1.3	6.6	5.9
500°	10.4	11.7	7.2	8.0	9.4	10.9
Same, Tp..	600°	14.3	16.7	10.0	13.0	13.7
	650°	15.6	20.4	11.2	14.3	14.1
	700°				9.8	10.6
	725°				8.6	9.8
860° Q <sub>o</sub> .....	8.9	10.1	0.8	1.0	3.6	4.5
300°	10.2	12.9	0.7	0.8		
400°	11.6	14.5	1.5	2.0		
Same, Tp..	500°	13.3	16.8	6.9	8.7	
	600°	14.5	18.2	10.1	12.3	13.8
	650°	15.1	20.4	11.3	13.6	16.2

For Ni, 3.5; C, 0.17 (845° Q<sub>o</sub> 760° Q<sub>o</sub> Tp 232°) IS (Izod) = 4.8.For Ni, 5; C, 0.16 (845° Q<sub>o</sub> 730° Q<sub>o</sub> Tp 232°) IS (Izod) = 10.5.

TABLE 12.—HIGH NI-STEELS

% composition			Trt	UTS	YP	EL <sub>a</sub>	RA	Lit.
Ni	C	Mn						
25-28	0.30			60-65	25-35	30-35	50-60	(6)
30-35	to			60-67	28-35	30-40	40-60	(6)
35-38	0.50			70-81	45-55	25-35	50	(6)
26	0.20	1.50	R <sub>h</sub>	55.2	8.4	50	71	(8)
30	0.15	1.50	A*	59.4	19.7	47	69	(8)
32.3	0.12	2.30	A*	54.5	15.5	43	66	(8)
35.1	0.22	1.50	A*	59.7	21.1	42	67	(8)
36	0.08	0.50	A*	50.9	16.9	39	68	(8)
45	0.37	1.50	A*	66.4	24.6	44	51	(8)
50.7	0.17	1.25	R <sub>h</sub>	69.6	34.1	39	68	(8)

\* Annealed from above 790°C.

Data on hardness of Ni-Fe alloys are unsatisfactory.

Approximate values are, for Ni, 10-20%: BHN = 200-350, ScH = 20-35; for Ni, 28-60%: BHN = 160-190, ScH = 16-24.

For Ni, 60-100%, hardness decreases continuously to that for pure Ni.

TABLE 13.—NI-MN ALLOYS\* (7, 19)

% composition					UTS	YP	PL	EL <sub>a</sub>	RA
Mn	C	Fe	Si	S					
3.00	0.06	0.62	0.22	0.018	52.1	16.5	14.1	51	60
3.58	.06	.62	.23	.018	52.3	16.7	15.8	50	62
4.40	.06	.73	.27	.021	53.1	19.3	17.6	43	63
5.06	.06	.72	.28	.020	54.5	18.8	15.8	48	62
6.78	.07	.89	.34	.020	57.6	21.8	21.4	50	66
6.84	.08	.91	.35	.020	57.1	22.1	21.9	36	56
9.18	.10	.95	.42	.021	59.1	23.1	22.5	48	62
9.24	.10	.94	.41	.020	58.9	23.0	21.8	48	64

\* For alloys of the typical composition: Mn, 0.3 to 10; Fe, 0.4; Co, 0.4; C, 0.1; Si, 0.1 the values of UTS, YP, and PL increase approximately 0.7 kg/mm<sup>2</sup> for each additional 1% Mn, while EL and RA are not changed appreciably. Although no data are available, the other properties may be accepted as substantially the same as for 99% nickel if Mn content is not over 10%. Alloys containing 2-6% Mn have tensile properties practically identical with those of Ni containing 0.3% Mn. These are commercially known as high Mn nickel, spark plug wire nickel, magno-nickel, etc.

## THERMAL PROPERTIES

Mold shrinkage = 2% of length for Ni, "Chromel," "Monel metal," and "Constantan" (5, 7, 19, 29).

TABLE 14.—ANNEALING AND FORGING RANGES (5, 7, 19, 29)

Metal	Ni	"Chro- mel"	"Monel metal"	"Con- stantan"
Annealing range, °C.....	500-700	600- 925	500- 700	500- 700
Forging range, °C.....	975-1200	975-1150	975-1150	925-1100

ANNEALING RANGES OF NICKEL SILVER (Cu-Ni-Zn) (2)

% Ni	% Zn	Ind. No.	Annealing range, °C	% Ni	% Zn	Ind. No.	Annealing range, °C
15	0	446	600-800	30	5	135	650-800
20	0	446	600-800	25	20	990	550-800
25	0	446	650-800	30	23	991	600-800
20	5	136	650-800	10	25	985	550-800
18	17	988	600-800	18	27	998	550-800

Annealing range depends on time and previous treatment, especially cold work. Ranges given above for Ni and Monel metal are the active annealing (softening) ranges. For R<sub>h</sub> or mildly R<sub>c</sub> metal: A 800-900°C; while for R<sub>c</sub> over 20%: A 700-800°. Neither Ni nor Monel metal is subject to heat treatment in the usual sense.

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(For key to the periodicals see end of volume)

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TABLE 15.—CRITICAL RANGES OF NI-STEELS

% composition						Heating rate, °/sec		Ac <sub>1</sub> , °C			Ac <sub>2</sub> Max.	Ac <sub>3</sub> , °C		Cool- ing, rate, °/sec	Ar <sub>3</sub> , °C		Ar <sub>1</sub> , °C			Lit.
Ni	C	Mn	Si	P	S	Range	Av.	Beg.	Max.	End		Max.	End		Beg.	Max.	Beg.	Max.	End	
0.00	0.40	0.00	0.008	0.00	0.00	0.09–0.21	0.15	733	736	746	767	788	809	0.16	767	745	708	704	694	(26)
.00	.40	.75	.22	.014	.022	0.075–0.30	.16	726	732	748	759	783	802	.14	743	729	681	672	654	
2.00	.38	.66	.16	.017	.011	0.10–0.23	.15	696	710	723		738	758	.16	691	670	642	630	599	(26)
2.04	.35	.65	.17	.010	.020	0.044–0.19	.12	699	709	721		742	758	.13	697	678	644	634	608	
2.68	.35	.64	.24	.014	.022	0.10–0.30	.19	691	704	716		737	758	.18	672	654	621	611	576	(26)
2.90	.40	.63	.28	.023	.033	0.16–0.20	.18	686	701	714		726	743	.19	670	644	617	606	572	
3.00	.37	.71	.22	.012	.010	0.11–0.26	.19	688	703	717		729	750	.18	668	641	616	609	567	(26)
3.46	.29	.56	.28	.018	.028	0.052–0.16	.096	684	695	710		730	750	.074	677	648	610	598	576	
3.31–	.15–	.34–		.006–	.025–	} Case (0.80 C)		678–701 (max.)			722–	732–794(max.)					583–631 (max.)			(3, 29)
3.75	.20	.60		.023	.033						738									
3.35–	.30–	.57–		.008–	.020–			677–710 (max.)			710–	710–745(max.)					584–610 (max.)			(3, 6, 24, 29)
3.70	.37	.70		.04	.045						745									
3.16–	.35–	.48–	0.10–	.009–	.020–			699–707 (max.)			716–	716–729(max.)					588–592 (max.)			(3, 6, 29)
3.65	.39	.65	0.22	.041	.036						729									
4.61–	.12–	.30–		.008–	.018–			670–692 (max.)			713–	740–760(max.)					555–576 (max.)			(29)
5.32	.17	.62		.046	.045						725									
								Same, for case												

## MECHANICAL AND THERMAL PROPERTIES OF CAST IRON AND OF STEELS CONTAINING C, CR, CR-V, CU, NI-CR, NI-CU, NI-V AND V

W. H. HATFIELD, J. WOOLMAN AND O. PRIEST

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### INTRODUCTION

**Order of Accuracy of Results Quoted.**—The term "order of accuracy" refers to the variations which are likely to arise from the method of testing *per se*. These variations may be due to slight changes in the apparatus, to the limits within which the observations may be read, to the sensitiveness of the apparatus, and to personal error. These do not affect the results in the same way, some giving a constant error and others a proportionate error.

**Variability of Results.**—It has not been possible to quote results with the order of accuracy attainable for the various tests. Variations in data arise not so much from errors of observation, but rather from slight differences in composition or small differences in heat treatment. Differences in heat treatment may be due to errors in temperature measurement or to varying rates of cooling. The size of the sample treated is in many cases of utmost importance. In the data given all test pieces, except where otherwise stated or indicated, were treated in the form of bars of about 1.5

in. diameter or of square section. Other variations in the rate of cooling may be due to the following causes:

In water quenching, to the temperature of the water.

In oil quenching, to different oils used, to their temperature and condition.

In air cooling, to the conditions of the atmosphere (temperature and nature of the draughts).

In furnace or slow cooling, to differences in the lagging.

In consequence of such possible variations, results by different observers on the same type of material often vary by considerable amounts, and for the same reasons in applying the results, one has to bear in mind the variations that may occur due to the above causes. The order of accuracy of the determinations and the variability of the results are tabulated below. The latter are quoted with a certain amount of reserve, but in most cases may be depended on as being of the right order. The term "Variability of Results" is not intended to apply to those cases of brittle steels where the test piece breaks prematurely.

## ACCURACY AND VARIABILITY OF RESULTS

 $\epsilon$  = Probable order of accuracy of determination. $\eta$  = Approximate variability of results.

Property	$\pm \epsilon$	$\pm \eta$
UTS, UCS	$\frac{1}{2}\%$	5 kg/mm <sup>2</sup>
YP, YP <sub>C</sub>	1%	5 kg/mm <sup>2</sup>
PL, EL	5%	10 kg/mm <sup>2</sup>
PL <sub>C</sub> , EL <sub>C</sub>	2%	10 kg/mm <sup>2</sup>
EL, RA	2	4
USS	1%	
TMR	1%	5 kg/mm <sup>2</sup>
YP <sub>S</sub>	2%	7 kg/mm <sup>2</sup>
PL <sub>S</sub> , EL <sub>S</sub>	5%	10 kg/mm <sup>2</sup>
<i>T<sub>w</sub></i>	1%	
E, G	2%	2%
BHN, LCH	1%	5%
ScH	5%	5%
<i>d</i> <sub>4</sub> <sup>20</sup>	0.1%	0.5%
<i>k</i>	2%	4%
<i>C</i>	2%	2%

**Torsion Test Data.**—The *maximum shearing strength* is obtained from tests on hollow specimens. In other cases, it has been calculated from results obtained on solid test pieces on the assumption that at the breaking point, the stresses are uniform across the section.

**Bend Tests on Cast Iron.**—Owing to the nature of this material, results of tests are very erratic, and the results quoted can only be taken as typical of the corresponding analysis.

**Impact Tests.**—In all cases, the actual energy to fracture the test piece is given. In the case of many observers, the results are quoted in energy units per unit area at the notch, but as results on different sizes of test pieces are not strictly comparable, nothing is gained by so reducing the results.

The different types of test pieces are indicated by subscripts, for meaning of which see p. 396.

**Approximate Variability of Results.**—Considerable variations are obtained, in many cases even in the same test piece, on material of similar composition and heat treatment. It is difficult, therefore, to give an estimate of the reliability of application in this case. The values quoted are, however, typical of the results to be obtained.

**Physical Data.**—*Specific Gravity.*—With great care in observation, density measurements can be made to an accuracy of below 0.01 %. It would appear, however, that most of the data available have been determined with an accuracy not greater than 0.1 %.

TABLE 1.—CHEMICAL ANALYSES

The analysis quoted for any given material, refers in most cases to the type of that material, and the range of composition covering that type has been given. It is to be understood that the actual amounts of any element may vary within small limits from the value quoted. In many cases where little published work is available, the actual analysis of the steel has been given.

## Carbon Steels

All these steels contain traces of S and P

Key No.	% composition			Ind. No.
	C	Mn	Si	
1	<0.07	0-0.2	Tr.	
2	0.08	0.4-0.6	Tr.	
3	0.09	0.1-0.4	Tr.	
4	0.14	0.1-0.3	0-0.3	
5	0.14	0.3-0.7	0-0.3	341

## Carbon Steels.—(Continued)

Key No.	% composition			Ind. No.
	C	Mn	Si	
6	0.18	0.7-0.8	0.1-0.2	341
7	0.18	0.1-0.6	0-0.4	
8	0.23	0.4-0.6	0.3	
9	0.25	0.4-0.6	Tr.	
10	0.25	0.1-0.2	Tr.	
11	0.28	0.17-0.26	0.03-0.04	
12	0.28	0.75-0.95	0.35	
13	0.30	0.4-0.6	0.10-0.3	
14	0.32	0.4-0.6	<0.3	
15	0.32	0.7-0.8	<0.4	
16	0.35	<0.4	0.15	
17	0.37	0.71	0.19	
18	0.38	0.2-0.25	<0.1	
19	0.38	0.4-0.6	<0.2	
20	0.40	0.43	0.33	
21	0.44	0.1-0.3	0.03-0.07	
22	0.44	0.46	0.275	
23	0.44	0.49	0.052	
24	0.45	0.7-0.9	0.12	
25	0.45	0.7-0.8	0.3-0.4	
26	0.45	0.35	0.65	
27	0.48	0.4-0.6	0.12-0.15	
28*	0.48	0.8-0.9	0.06-0.1	
29	0.49	0.1-0.2	<0.10	
30	0.49	0.70	0.34	
31	0.50	0.43	0.24	
32*	0.52	0.5-0.7	0.2-0.3	
33	0.53	0.48	0.12	
34	0.54	0.1-0.2	0.03-0.08	
35	0.55	0.8-0.9	0.2-0.3	
36	0.55	0.44	0.86	
37	0.58	0.1-0.3	<0.2	
38	0.59	0.4-0.6	<0.49	
39†	0.60	0.7-0.8	0.20	
40	0.63	0.8-0.9	0.1-0.2	
41	0.63	0.4-0.65	<0.3	
42	0.64	0.18	0.336	
43	0.65	0.26	<0.06	
44	0.65	0.48	0.08	
45	0.67	0.66	0.07	
46	0.70	0.12-0.26	<0.3	
47	0.71	0.67	0.147	
48‡	0.73	0.74	0.313	
49	0.75	0.1-0.35	<0.100	
50§	0.78	0.71	0.322	
51	0.79	0.2-0.4	<0.38	
52	0.81	0.87	0.22	
53	0.84	<0.3	<0.3	
54	0.84	0.5-0.65	<0.2	
55	0.86	0.07	0.056	
56	0.87	0.7-0.8	0.06-0.07	
57	0.89	0.19	0.34	
58	0.90	0.3-0.5	<0.3	
59	0.93	0.45-0.6	<0.3	
60	0.94	0.2-0.4	<0.3	
61	0.98	0.43	0.158	
62	1.00	0.4-0.6	0.5	
63	1.00	0.2-0.35	<0.2	
64	1.02	0.2-0.4	<0.3	
65	1.10	0.35	0.059	
66	1.11	0.23	0.27	



## Carbon Steels.—(Continued)

Key No.	% composition			Ind. No.
	C	Mn	Si	
67	1.18	0.050	0.094	
68	1.20	0.2-0.44	0.2-0.3	
69	1.22	0.1-0.3	<0.2	
70	1.25	0.62	0.46	
71	1.26			
72	1.28	0.8	0.06	
73	1.29	0.22	0.31	
74	1.30	0.3-0.4	<0.1	
75	1.35	0.54	0.26	
76	1.40	0.2-0.45	Up to 0.2	
77	1.50	0.64		
78	1.50	0.2-0.3	0.1-0.2	
79	1.60	0.55	0.085	
80	1.70	0.29	0.08	
81	1.76	0.07	0.058	
82	1.95	0.02	0.034	
83	2.10	0.58	0.078	

\* Rails.

† Tram rails.

‡ R. R. tire.

§ Tram tire.

## Cast Iron

Key No.	10 × % composition						Ind. No.
	Total C	Graph-ite	Mn	Si	S	P	
84	23	9-11		20-25		18-22	
85	24	13		20		29	
86	24-25	9-10		10-16		17-20	
87	25	19	3	10	Tr.	3.0	
88	26-27	14-16		20-23		10-11	
89	27	8.5		20	4.5		
90	27-29	16-20		11-14		<12	
91	27-29	16-18		20-24	<1.8	<5	
92	29-30	4-7		12-15	<1.5		
93	29	24	5	29	1.5	1.8	
94	29	29	5	15		Tr.	
95	30-31	2.5-4.5		6-8	<1.0		
96	29-31	17-21		8-19	1.1		
97	30-31	26-28	6-10	15-23			
98	31	11	20	10			
99	32	15		13.5	0.5		
100	30-32	21-24	4-8	13-20	1-2	1-9	
101	28-35		<1.5	6-8	<3.5	<2	837
102	28-35		<4	6-8	<0.7	<2	836
103	32	Tr.		4	Tr.	Tr.	1477
104	32	11	3.5	8			
105	30-32	23-24	20-22	17-24			
106	30-33	27	2-9	11-20	1-2	<15	
107	32-33	27-29	5-7	22-27	1.0	2-8	
108	32-34	20-25	0-9	10-14	0.5-1.7	4-8	
109	33-34	25-26	5-6	20-22	1-1.3	8-11	661
110	33.5	29-30	6	24-28	1.0	2.0	
111	34-35	27-29	6	14-15	<1.4	1-4	
112	34-35	28-31	6-7	19-25	<1.5	1.5-5.5	
113	35	33	6.5	22-26	<1.0	3-5	
114	36-33.5	29-30	6-9	12-15	1-1.6	1-4	
115	36.5	35	5	29	6.2	13	
116	37.5	27.3	5	16	1.0	4.9	
117*	35-38	30-32	6-7	5-6	2-2.2	3.4-3.7	
118	35-33	32-33	8	13-15	1.4-1.9	1.3-1.6	
119	45.7						

\* Chilled iron car wheels.

## Chromium Steels

Analyses show traces of S and P in all these Cr steels excepting Nos. 146, 170, 184, 185, 189, 191.

Key No.	% composition				Ind. No.
	Cr	C	Mn	Si	
120	0.25	0.36	0.34	0.15	
121	0.35	1.46	0.2	0.13	
122	0.5	0.36	0.32	0.19	
123	0.6	0.64	0.10	0.04	
124	0.6	0.86	0.03	0.24	
125	0.70	0.04	Tr.	0.97	
126	0.76	0.35	0.3	0.15	
127	0.9	0.47	0.72		
128	1.0	0.34	0.32	0.05	
129	1.0	0.6			
130	1.0	0.84	0.1	0.06	
131	1.0	0.97	0.24	0.22	
132	1.2	0.06	Tr.	0.7	
133	1.3	0.45	0.72	0.12	
134	1.3	0.75	0.34	0.16	
135	1.4	0.31	0.75	0.14	
136	1.5	0.35	0.25	0.1	
137	2.0	0.22	0.2	Tr.	
138	2.0	0.33	0.2	0.05	
139	2.0	0.50	0.24	Tr.	
140	2.0	0.65	0.2	Tr.	
141	2.0	0.95	0.2	0.18	
142	2.35	0.83	0.35	0.2	1437
143	2.6	0.39	0.18	0.07	
144	2.7	0.25	0.2	0.05	
145	3.0	0.4	0.2	0.1	
146	3.0	0.6			
147	4.0	0.31	0.2	0.2	
148	4.0	0.40	0.2	0.08	
149	4.0	1.00	0.1	0.22	
150	4.5	0.21	Tr.	0.23	
151	4.6	0.79	Tr.	0.42	
152	5.0	0.34	0.43	Tr.	
153	5.0	0.46	0.18	0.11	
154	5.0	0.83	0.10	0.08	
155	5.0	1.07	0.21	0.19	
156	5.4	0.25	0.19	0.19	
157	5.8	0.57	0.22	0.12	
158	6.3	0.26	0.16	0.20	
159	6.3	0.40	0.3	0.25	
160	6.3	0.54		0.14	1444
161	6.3	1.00	0.14	0.3	1444
162	7.3	0.84	0.06	0.41	
163	7.8	0.07	Tr.	0.12	
164	8.1	0.43	0.25	0.43	
165	8.1	1.02	0.1	0.37	
166	9.1	0.14	Tr.	0.34	
167	9.4	0.75	Tr.	0.88	
168	9.5	0.44		0.24	
169	9.5	1.09	0.1	0.45	
170	10	0.6			
171	10.15	0.15	Tr.	0.2	
172	10.15	0.85	<0.1	0.11	
173	10.4	0.37	0.19	0.50	
174	10.4	1.14	0.07	0.46	
175	11.2	0.36		0.16	1443
176	11.8	1.01	0.28	0.06	
177	12-14	0.08	0.1		1323

## Chromium Steels.—(Continued)

Key No.	% composition				Ind. No.
	Cr	C	Mn	Si	
178	12-14	0.12	0.13	0.16	1324
179	12-14	0.28	0.22	0.1	
180	12-14	0.34	0.24	0.5	
181	12-14	0.39	0.24	0.5	
182	12-14	0.12	0.26	1.31	1324
183	12-14	0.32	0.22	1.19	
184	12-14	1.18		0.1	1443
185	15.0	0.6			
186	15.0	0.88	<0.1	0.03	
187	16.0	0.47	0.64	0.24	
188	19.5	0.85	<0.1	0.1	
189	20	0.6			
190	23.7	0.85	<0.1	0.20	
191	29.5				507

## Chrome Vanadium Steels

Key No.	% composition							Ind. No.
	Cr	V	C	Mn	Si	S	P	
192	0.30	0.11	0.20	0.25	Tr.	Tr.	Tr.	
193	0.5	0.15	0.72					
194	0.6	0.16	0.23	0.36	Tr.	Tr.	Tr.	
195*	0.9	0.17	0.35	0.78		Tr.	Tr.	
196	1.0	0.17	0.22	0.29	0.1	Tr.	Tr.	
197	1.0	0.17	0.37	0.74	0.21	Tr.	Tr.	
198	1.0	0.19	0.44	0.84	0.17	Tr.	Tr.	
199	1.1	0.17	0.30	0.39	0.06			
200	1.3	0.19	0.38	0.47	0.06	Tr.	Tr.	
201	1.2-1.4	0.16-0.20	0.37-0.42	0.60-0.85	<0.3	<0.05	<0.05	
202	1.45	0.19	0.46	0.45	0.18			
203	1.5	0.33	0.46	0.64	0.19	Tr.	Tr.	

\* Connecting rod.

## Copper Steels

Analyses show traces of S in all these excepting Nos. 217, 219, 223, 235-237, 239, 240.

Key No.	% composition					Ind. No.
	Cu	C	Mn	Si	P	
204	0.1	0.78	0.52	0.07	Tr.	
205	0.2	0.13	0.50	0.25	Tr.	
206	0.2	0.30	0.30	0.26	0.08	
207	0.2	0.49	0.43	0.07	Tr.	
208	0.2	0.50	0.02	0.07	0.20	
209	0.2	0.50	0.79	0.27	Tr.	
210	0.3	0.72	0.83	0.03	Tr.	
211	0.4	0.29	0.34	0.26	0.08	
212	0.4	0.49	0.46	0.08	Tr.	
213	0.4	0.72	0.46	0.05	Tr.	
214	0.5	0.16	0.09	0.22	Tr.	
215	0.5	0.39	0.14	0.32	Tr.	
216	0.5	0.42	0.93	0.06	0.07	
217	0.5	0.57	0.02	0.31		
218	0.5	0.97	0.49	0.18	Tr.	
219	0.5	1.03	0.06	0.32		
220	0.6	0.28	0.30	0.21	0.07	
221	0.6	0.52	0.43	0.07	Tr.	
222	0.7	0.28	0.26	0.27	Tr.	
223	0.85	0.10				
224	0.9	0.48	0.7	0.07	Tr.	
225	1.0	0.16	0.07	0.21	Tr.	
226	1.0	0.40	0.16	0.31	Tr.	
227	1.0	0.54	0.32	<0.26	Tr.	
228	1.0	1.00	0.30	0.29	Tr.	
229	1.3	0.32	0.64	Tr.	Tr.	
230	1.6	0.68	0.36	Tr.	Tr.	
231	1.8	0.10	0.08	0.04	Tr.	

## Copper Steels.—(Continued)

Key. No.	% composition					Ind. No.
	Cu	C	Mn	Si	P	
232	2.0	0.17	0.11	0.21	Tr.	
233	2.0	0.29	0.68	0.08	0.08	
234	2.0	0.39	0.18	0.24	Tr.	
235	2.1	0.22				
236	2.5	0.59	0.32	0.07		
237	2.9	0.17	1.04	0.15		
238	3.0	1.07	0.31	0.34	Tr.	
239	3.7	0.04	0.16			
240	3.7	0.38				
241	4.0	0.16	0.11	0.19	Tr.	
242	4.0	0.37	0.14	0.22	Tr.	

## Nickel Chromium Steels

All these Ni-Cr steels contain traces of P and S.

Key No.	% composition					Ind. No.
	Ni	Cr	C	Mn	Si	
243	0.73	0.17	0.19	0.48		
244	1.5-1.8	0.6	0.30	0.5	0.2	
245	1.5-1.8	0.8	0.28	0.4	0.1	
246	1.5-1.8	1.6	0.38	0.6	0.33	
247	1.9-2.1	0.6	0.37	0.7	0.18	
248	1.9-2.1	1.0	0.21	0.4	0.20	
249	1.9-2.1	1.0	0.36	0.4	0.47	
250	1.9-2.1	1.0	0.42	0.84	0.26	
251	1.9-2.1	2.2	0.44	0.67	0.14	
252	2.1-2.4	0.5	0.30	0.4	0.1-0.25	
253	2.1-2.4	1.45	0.30	0.45	0.24	
254	2.8-3.2	0.45	0.17	0.4	0.15	
255	2.8-3.2	0.34	0.37	0.4	0.12	
256	2.8-3.2	0.9	0.39	0.6	0.23	
257	2.8-3.2	1.4	0.30	0.6	0.14	
258	2.8-3.2	1.5	0.35	0.4	0.25	
259	2.8-3.2	2.0	0.35	0.3	0.3	
260	2.8-3.2	1.7	0.5	0.3	0.3	
261	3.7	0.6	0.17	0.3	0.1	
262	3.3-3.7	0.6-1.0	0.23-0.27	0.4-0.6	0.1-0.2	
263	3.3-3.7	0.7-1.0	0.3-0.34	0.4-0.7	0.1-0.14	
264	3.3-3.7	1.4-1.6	0.26	0.3	0.1	
265	3.7-4.1	0.9	0.38	0.7	0.15	
266	3.7-4.1	1.4-1.6	0.14	0.4	0.1	
267	3.7-4.1	1.4-1.6	0.31	0.4	0.1	31
268	4.0	2.0	0.27	0.5	0.13	
269	4.7	1.5	0.35	0.6	0.2	
270	5	1	0.2	0.3	0.06	
271	5	20	0.3	0.1	0.08	
272	9.6	23	0.40			
273	16	3	0.5	0.8	0.4	
274	23-25	1.3-1.5	0.9-1.0	1.7-2.0	0.4	
275	23-25	1.3-1.5	0.5	0.24	0.4	
276	30-33	2-3	0.6	0.04	0.25	
277	36	12	0.75		1-2	537

## Nickel Copper Steels

Key No.	% composition							Ind. No.
	Ni	Cu	C	Mn	Si	S	P	
279	1.0	0.4	0.45			Tr.		
280	2.26					Tr.		
281	1.7	0.7	0.43			Tr.		
282	1.8	1.7	0.63		0.30	0.06		
283	1.9	1.35	0.45	0.84	1.10	Tr.	Tr.	



## Nickel Copper Steels.—(Continued)

Key No.	% composition							Ind. No.
	Ni	Cu	C	Mn	Si	S	P	
284	2.0	1.3	0.76					
285	2.1	0.17	0.15	0.91	0.15	Tr.	Tr.	
286	2.1	1.2	0.43					
287	2.3	1.0	0.56	0.48	0.37	0.07		
288	2.4	0.20	0.16	0.77	0.14	Tr.	Tr.	
289	2.45	0.55	0.49	1.03	1.25	Tr.	Tr.	
290	2.45	0.6	0.58	0.90	0.23	Tr.	Tr.	
291	2.45	0.8	0.53		0.21	Tr.		
292	2.5	0.19	0.17	1.07	0.18	Tr.	Tr.	
293	2.5	0.9	0.57	0.33	0.07	0.07		
294	2.5	1.0	0.45			Tr.		
295	2.55	0.6	0.46	0.82	1.30	Tr.	Tr.	
296	2.6	0.36	0.50	0.78	1.25	Tr.	Tr.	
297	2.7	0.6	0.57		0.44	Tr.		
298	2.9	0.5	0.38		0.28	Tr.		
299	2.9	0.6	0.51	1.04	1.35	Tr.	Tr.	
300	3.0	0.7	0.76		0.24		0.1	
301	3.45	0.27	0.43	0.27		Tr.	Tr.	
302	3.6	0.5	0.44	0.50	0.03	Tr.	Tr.	
303	3.9	0.30	0.53	0.79		0.06	Tr.	
304	22.0	9.0	0.22					
305	25	10	0.2					

## Iron and Monel Metal (M. M.)

Monel metal contains Ni, 67-68%; Cu, 24-26; Fe, 28-5; Mn, 1.6-2.2.

Key No.	% composition					
	C	M. M.	Key No.	M. M.	Key No.	M. M.
306		2	311	6	316	16
307	0.15	2	312	8	317	18
308	0.10	3	313	10	318	20
309		4	314	12		
310	0.67	4	315	14		

## Nickel Vanadium Steels

All these Ni-V steels have traces of P and S except No. 323 which has 0.111% S.

Key No.	% composition				
	Ni	V	C	Mn	Si
319	2.0	0.60	0.15	0.45	0.22
320	2.1	0.30	0.72	0.53	0.41
321	2.2	0.17	0.37	1.4	0.16
322	2.2	7.5	1.25	0.70	0.61
323	2.3	0.35	0.26	0.45	0.54
324	2.3	3.1	0.47	0.54	0.29
325	2.4	0.23	0.45	1.3	0.23
326	2.6	0.68	0.44	0.42	0.22
327	2.6	1.45	0.86	0.65	0.36
328	2.6	6.9	0.38	0.57	0.53
329	2.7	2.9	0.89	0.61	0.40
330	2.9	0.34	0.41	0.25	0.35
331	3.0	0.30	0.38	0.79	1.35
332	3.1	0.21	0.56	1.14	1.09
333	3.15	0.32	0.60	0.79	1.30
334	3.4	0.28	0.24	0.48	0.1
335	3.4	0.60	0.33	0.1	0.12
336	3.6	0.13	0.40	0.1	0.40
337	5.5	0.35	0.19	0.16	0.07
338	6.1	0.60	0.17	0.15	0.07
339	6.2	0.12	0.16	0.13	0.06

## Vanadium Steels

Key No.	% composition						Ind. No.
	V	C	Mn	Si	S	P	
340	0.12	0.22	0.72		Tr.	Tr.	
341	0.14	1.06	0.05	0.1	Tr.	Tr.	
342	0.16	0.09	0.21	0.1	Tr.	Tr.	
343	0.16	0.23	0.16	0.1	Tr.	Tr.	
344	0.18	0.33	0.77	0.32	Tr.	Tr.	
345	0.20	1.32	0.33	0.1	Tr.	Tr.	
346	0.21	0.56	0.30	0.1	Tr.	Tr.	
347	0.21	0.98	0.38	0.1	Tr.	Tr.	
348	0.22	0.71	0.31	0.1	Tr.	Tr.	
349	0.23	0.40	0.30	0.1	Tr.	Tr.	
350	0.25	0.82	0.45	0.33	Tr.	Tr.	
351	0.27	0.20	0.48	0.1	Tr.	Tr.	
352	0.3	0.11	0.12	0.11	Tr.	Tr.	
353	0.3	0.45	0.46	0.38			
354	0.3	1.02	0.05	0.1	Tr.	Tr.	
355	0.35	0.74					
356	0.6	0.13	0.36	0.19	Tr.	Tr.	
357	0.6	0.18	0.43	0.15	Tr.	Tr.	
358	0.6	0.72	0.56	0.41	Tr.	Tr.	
359	0.6	1.00	0.05	0.1	Tr.	Tr.	
360	0.7	0.60	0.06	0.05	Tr.	Tr.	
361	0.75	0.14	0.45	0.30	Tr.	Tr.	
362	0.8	0.89	0.33	0.30	Tr.	Tr.	
363	0.8	1.04	0.05	0.1	Tr.	Tr.	
364	0.85	0.05	0.05	0.1	Tr.	Tr.	
365	1.0	0.11	0.38	0.26	Tr.	Tr.	
366	1.1	0.80	0.05	0.1	Tr.	Tr.	
367	1.2	0.67	0.50	0.25	Tr.	Tr.	
368	1.5	0.13	0.30	0.25	Tr.	Tr.	
369	1.6	0.62	0.34	0.29	Tr.	Tr.	
370	2.1	0.20	Tr.	0.22	Tr.	Tr.	
371	2.3	0.63	0.07	0.09	Tr.	Tr.	
372	2.9	0.95	0.22	0.42	Tr.	Tr.	
373	3.0	0.19	0.86	0.29	Tr.	0.08	
374	3.0	0.67	0.70	0.36	Tr.	Tr.	
375	5.0	1.08	0.45	0.46	Tr.	Tr.	
376	5.4	0.38	0.20	0.61	Tr.	0.07	
377	5.8	0.93	0.11	0.21	Tr.	Tr.	
378	7.4	0.13	Tr.	0.41	Tr.	0.11	
379	7.8	0.74	0.31	0.74	Tr.	0.12	
380	10.25	0.12	Tr.	0.54	Tr.	Tr.	
381	10.25	0.86	0.56	0.99	Tr.	Tr.	
382	10.25	1.07	0.12	0.32	Tr.	Tr.	
383	13.5	1.10	0.12	0.47	Tr.	Tr.	

TABLE 2, PART I.—CARBON STEELS (TENSILE PROPERTIES)

Key No.	Treatment	UTS	YP	PL	EL	El	RA	Lit.
1	As cast.....	29.4	17.7			24.5	33	(7, 18, 68, 118, 122)
	Cast, A 950°.....	28.4	14.3			32	48	
	Before D <sub>c</sub> .....	39.6	26.7	20.5		36.5	69	
	D <sub>c</sub> 14.8%.....	55.4	51.0	31.6		17	54	
	Same, A { 100° 200° 300° 450° 550° 600° 650° } 60 m	56.6	50.3	34.7		21	59	
		56.0	50.3	33.0		20	57	
		55.4	50.3	39.4		21	55	
		56.0	43.5	36.2		26	66	
		47.9	42.2	34.6		28	66	
		43.5	35.2	17.3		30	69	
		37.2	19.8	11.0		42	73	
	Normalized.....	34.5	22.5	11.3	10.1	37	73	
	1½ in. { 920° Q <sub>w</sub> diam. { 920° Q <sub>o</sub>	55.0				30	67	
		47.2				35	69	





TABLE 2, PART I.—CARBON STEELS (TENSILE PROPERTIES).—  
(Continued)

Key No.	Treatment	UTS	YP	PL	EL	EL	RA	Lit.
7	350°.....	42.6	25.7	24.6		30f-37d	61.5	(141)
	500-540°....	40.9	22.6			48a-35c	63	
	680°.....	39.7	21.1			47a-33c	66	
	750°.....	48.5	27.4	27.5		31f-38.5d	62	
	800-820°....	39.8	22.2			46a-33c	64.5	
	850°.....	41.5	26.0	21.8		30f-37d	60.5	
	Cast A 950°....	30.7	14.7			31a	47	
	A 1000°.....	44.6	33.1	26.7		31f-38d	64	
	750° Q <sub>w</sub> .....	56.3	33.0	12.5		16f-19d	52	
	Same, Tp	350°.....	43.2	25.8	16.8	26.5f-33d	62	
		550°.....	41.9	25.7	26.6	29f-36d	63	
		650°.....	42.8	25.6	21.1	30.5f-37d	60.5	
	750° Q <sub>o</sub> 80°....	49.3	29.5	24.6		21.5f-26d	58	
	Same, Tp	350°.....	42.0	24.5	21.1	28.5f-35d	63	
		550°.....	41.0	25.8	21.1	30f-37.5d	62	
	790° Q <sub>o</sub> 260°....	65.2		34.0		26	57	
	Same, Tp	540°.....	62.0		42.2	28	60.5	
		650°.....	59.4		37.6	34	65	
	1000° Q <sub>w</sub> .....	61.8	44.5	16.3		11f-17.5d	65.5	
	Same, Tp	350°.....	57.4	39.1	19.8	14f-20.5d	66	
		550°.....	58.1	42.2	25.9	16.5f-21d	66.5	
		650°.....	52.4	39.6	36.6	20.5f-32d	69	
	1000° Q <sub>o</sub> 80°....	51.3	37.8	25.3		25f-33d	65	
	Same, Tp	350°.....	53.8	38.6	30.7	21f-27.5d	67.5	
		550°.....	51.9	37.1	25.7	21.5f-29d	67.5	
	D <sub>o</sub> .....	61.0	None		36.6	14a	49	
	D <sub>o</sub> A 705°.....	39.8	20.7	18.8	18.2	41a	65.5	
	D <sub>o</sub> A 845°.....	40.5	21.1	19.7	18.0	41a	63	

v. also Fig. 2

8	Cast (v. also Fig. 2).....	38.9	16.2	9.0		12	13.5	(41, 67, 141)
	Cast, A	Large..	44.4	21.6	17.1	31	49	
		Small..	49.4	25.2	21.5	35.5	53	
	R <sub>h</sub> .....	52.0	27.6	20.7		25f-30d	51	
	A	350°.....	49.6	27.5	25.6	26f-33d	58	
		750°.....	47.7	26.3	23.7	28f-35d	59	
		850°.....	49.6	27.7	20.8	27f-33d	51	
		1000°.....	53.3	34.2	30.1	26f-32d	51	
	750° Q <sub>w</sub> .....	58.8	36.2	15.7		20f-22d	53	
	Same, Tp	350°.....	49.2	28.2	15.8	25f-31d	58	
		550°.....	48.5	27.0	23.6	27.5f-35d	59	
		650°.....	50.8	27.6	17.7	27f-33.5d	56	
	750° Q <sub>o</sub> 80°....	51.2	29.8	23.6		21.5f-27d	58	
	Same, Tp	350°.....	48.2	27.9	25.6	27f-33d	59	
		550°.....	50.0	26.8	21.7	27f-34d	57	
	850° Q <sub>w</sub> .....	73.4	41.6	15.8		6f-8.5d	14	
	Same, Tp	350°.....	119.8	101.0	29.7	4f-6d	27	
		550°.....	78.9	61.3	49.4	10f-15d	50	
		650°.....	65.2	45.4	35.6	15f-20d	58	
	850° Q <sub>o</sub> 80°....	66.0	43.3	15.7		14f-20d	51	
	Same, Tp	350°.....	68.0	42.4	21.7	16f-21d	57	
		550°.....	64.0	39.3	31.4	17f-23d	55	
	1000° Q <sub>w</sub> .....	76.0	48.4	16.8		11f-15d	49	
	Same, Tp	350°.....	116.2	83.4	33.8	4f-7d	36	
		550°.....	73.4	50.6	39.7	14f-18d	62	
		650°.....	67.4	49.5	41.6	15f-20d	65	
	1000° Q <sub>o</sub> 80°....	68.6	46.7	37.7		16.5f-22d	56.5	
	Same, Tp	350°.....	71.1	47.4	37.5	15f-20d	52	
		550°.....	66.9	45.4	41.4	14f-19d	55	
9	R (v. Fig. 3).....	43.1	20.6			43a-38b-32c	57	(26)
	760°/30 Cf.....	41.9	21.8			42a-37b-32c	58	
	500°/30 C <sub>a</sub> .....	42.6	21.3			44a-38b-33c	57	
	700°/30 C <sub>a</sub> .....	40.3	19.6			45a-41b-35c	59	
	As received.....	45.7		28.2		29	63	
	800°/2 Q.....	61.2		45.3		4.5		
	800°/20 Q.....	72		53.6		2.5		
	800°/60 Q.....	71.2		46		2		
	950°/2 Q.....	101.3		68.8		2	5	
	950°/20 Q.....	120.3		90		3.5	10	
	950°/60 Q.....	128.1		95.7		3?	7?	

TABLE 2, PART I.—CARBON STEELS (TENSILE PROPERTIES).—  
(Continued)

Key No.	Treatment	UTS	YP	PL	EL	EL	RA	Lit.
10	As received.....	46.5		28.1		24	53	(120)
	800°/2 Q.....	58		34.3		16	57	
	800°/20 Q.....	62		39		16.5	57	
	800°/60 Q.....	58.6		36.2		18.5	60	
11	R 5 SWG.....	48.8				39	58	(97)
	Same, A.....	37.8				37	73	
	25 SWG wire....	72.8				4		
12	R (v. also Fig. 4).	51.9	23.0			15g	30	(113, 114)
	A	750°.....	51.6			26g	51	
		800°.....	53.2			22g	52	
		850°.....	50.5	28.2		21g	50	
		950°.....	53.2			20g	46	
		1000°.....	53.9			19.5g	44	
	N 900°.....	55.9	38.6			32a	59	
	900° Q <sub>w</sub> .....					11a	30	
	Same, Tp	300°.....				12a	32	
		400°.....	59.8			15a	44	
		500°.....	56.6			23a	58	
		600°.....	67.7	48.8		28a	64	
	900° Q <sub>o</sub> .....	69.3				25a	55	
	Same, Tp	300°.....	69.3			26a	57	
		400°.....	69.3			26a	59	
		500°.....	67.7	48.8		27a	60	
		600°.....	63.0	44.1		29a	64	
13	N 870°.....	53.5	34.6			34	58	(46, 60, 67, 75)
	870° Q <sub>w</sub> .....	69.2				24	56	
	Same, Tp	300°.....	67.7			24	57	
		400°.....	69.2			25	58	
		500°.....	66.1	50.4		27	60	
		600°.....	63.0	45.6		29	64	
		700°.....	58.2	40.8		33	68	
	870° Q <sub>o</sub> .....	64.5				28	60	
	Same, Tp	300°.....	64.5			28	60	
		400°.....	64.5			28	61	

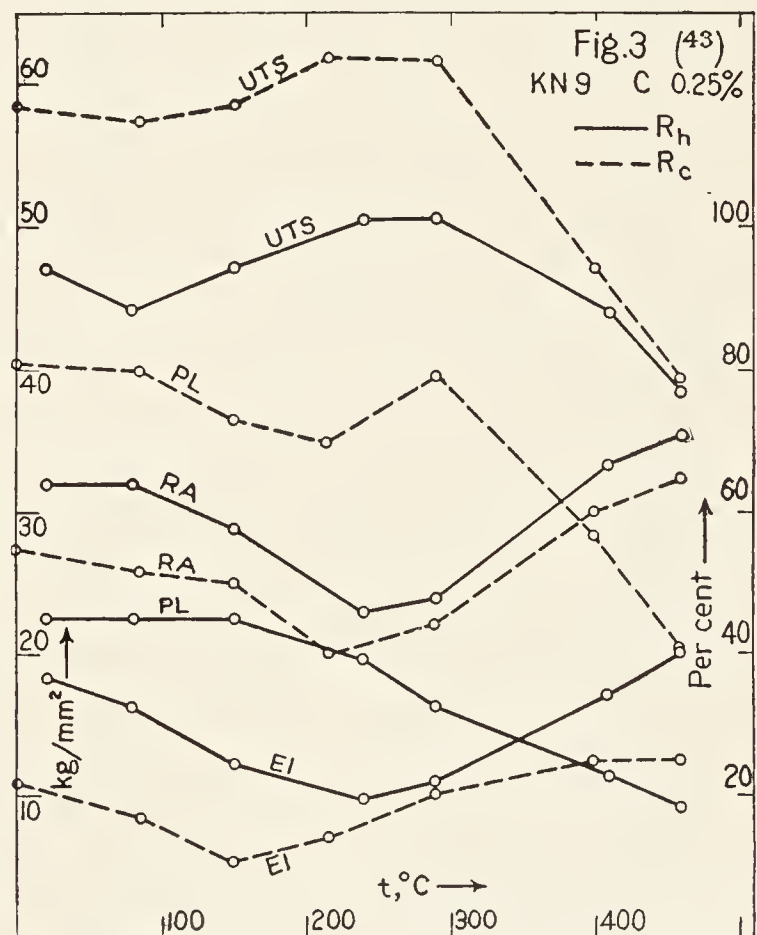


TABLE 2, PART I.—CARBON STEELS (TENSILE PROPERTIES).—  
(Continued)

Key No.	Treatment	UTS	YP	PL	EL	El	RA	Lit.
13	Same, { 500°....	63.0	45.6			29	61	
	Tp { 600°....	61.4	42.5			31	63	
	Cont'd. { 700°....	56.6	39.4			34	68	
	R <sub>h</sub> 15 mm diam.	48.7	32.8	25.7	26.2	30	59.5	
	D <sub>0</sub> { 14.3 mm diam.....	62.8		26.5	26.2	13	49	
				29.5	31.4	9	43	
		68.0		33.7	34.0	4.5	39	
				39.0	38.8	4.5	35	
		73.0		48.9	46.0	3	25	
				57.0	55.4	3	23	
		74.6						
	F, longitudinal...	44.6	21.5	18.6		33.5	53	
	F, transverse....	40.1	17.0	12.6		22.5	33.5	
	v. also Fig. 30							
14	R <sub>h</sub> .....	55.1	28.0	18.7		24f-30d	53	(49, 91,
	A { 350°.....	55.0	29.5	25.6		26f-31.5d	55	111,
		52.6	28.4	24.6		25f-31d	55	141,
		53.1	26.5	21.8		26f-32d	54	146)
		48.7	21.3	15.7		33 <sub>a</sub>	51	
		57.3	34.2	30.1		26f-32d	57.5	
	750° Q <sub>w</sub> .....	61.8	40.3	15.7		19f-23d	52	
	Same, { 350°.....	54.7	27.2	17.7		25f-30d	55	
		53.7	27.5	21.6		24f-30.5d	55	
		54.1	29.6	21.7		25f-31d	52	
	750° Q <sub>o</sub> 80°.....	54.8	28.1	22.3		34 <sub>a</sub>	55	
	Same, { 350°.....	53.7	28.2	21.7		26f-32d	55	
		53.3	26.6	25.6		24f-31d	55	
						38 <sub>a</sub>	63	
		47.7	22.2	17.3		35 <sub>a</sub>	62	
	650° C <sub>f</sub> .....	49.6	24.5	17.3				
	850° Q <sub>w</sub> .....	95.2				8 <sub>a</sub>	17	
	850° Q <sub>o</sub> 80°.....	74.5	50.2	31.5		23.5 <sub>a</sub>	62	
	Same, { 350°.....	72.8	49.5	29.5		22.5 <sub>a</sub>	62	
		69.6	47.1			23 <sub>a</sub>	62	
		68.9	47.0	43.3		26.5 <sub>a</sub>	65	
		59.0	43.2			30 <sub>a</sub>	71	
	870° Q <sub>w</sub> .....	141.0	128.3	87.3		3 <sub>a</sub>	2.5	
	Same, { 400°.....	103.9	90.0	74.1		7.5 <sub>a</sub>	27	
		99.6	86.6	67.0		17 <sub>a</sub>	18	
		79.0	57.1	54.3		13 <sub>a</sub>	26	
	900° Q <sub>o</sub> 650°/120							
	Q <sub>w</sub> .....	55.4	32.4	25.2		33 <sub>a</sub>	64	
	Same, but C <sub>f</sub>							
	1°/m.....	52.4	28.9	25.2		33 <sub>a</sub>	65	
	1020° Q <sub>o</sub> , Tp							
	650°/120 Q <sub>w</sub> ....	52.1	28.9	22.1		35 <sub>a</sub>	64	
	1250° Q <sub>o</sub> , Tp							
	650°/120 Q <sub>w</sub> ....	55.2	33.7	22.1		30 <sub>a</sub>	61	
	Same, but C <sub>f</sub>							
	1°/m.....	49.7	28.7	18.9		38 <sub>a</sub>	63	
15	As cast.....	53.6	23.6	14.0		26	34	(65, 86,
	A 925° C <sub>f</sub> .....	56.1	29.0	26.1		27	39.5	95,
	N 925° C <sub>a</sub> .....	59.7	32.2	28.5		28	46	146)
	N 850°.....	55.8	32.9	31.8		30.5	55	
	A 816°.....	40.5	21.7			15	27	
	A 893° { 870° Q <sub>w</sub> ,	61.7	43.5			4	8	
		65.2	43.1			12	15	
	A 871° { 482° Tp							
	Wire 5 mm diam.	62.8				6	12	
	A 800-900°.....	47.9				18	60	
	750° Q <sub>o</sub> .....	74.4				7	48	
	850° Q <sub>w</sub> .....	120.7				0	0	
	950° Q <sub>w</sub> .....	145.3				0	0	
	Same, { 100°.....	168.6				3	12	
		155.6				6	27.5	
		134.4				8.5	36.5	
		111.2				10	48	

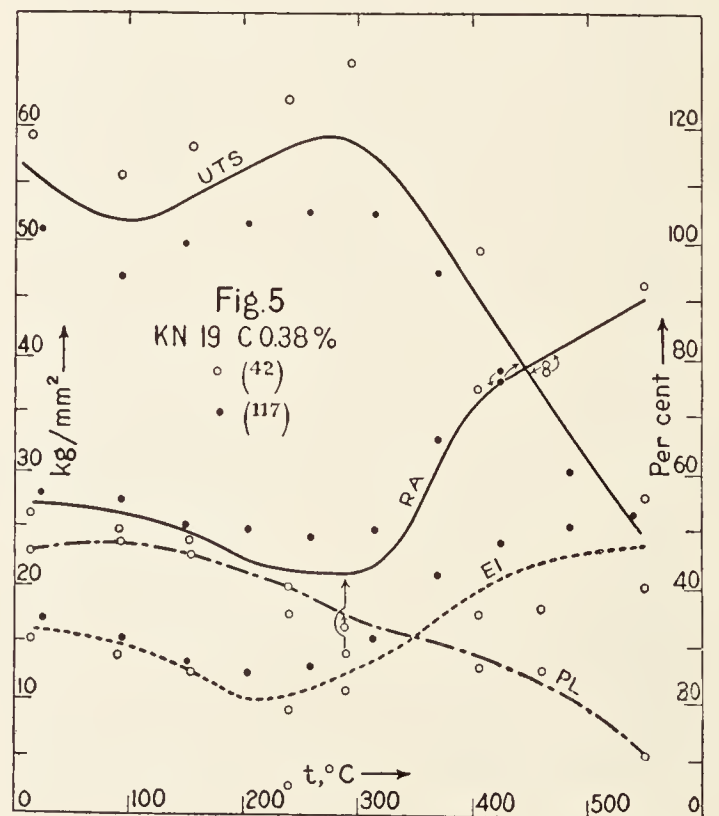
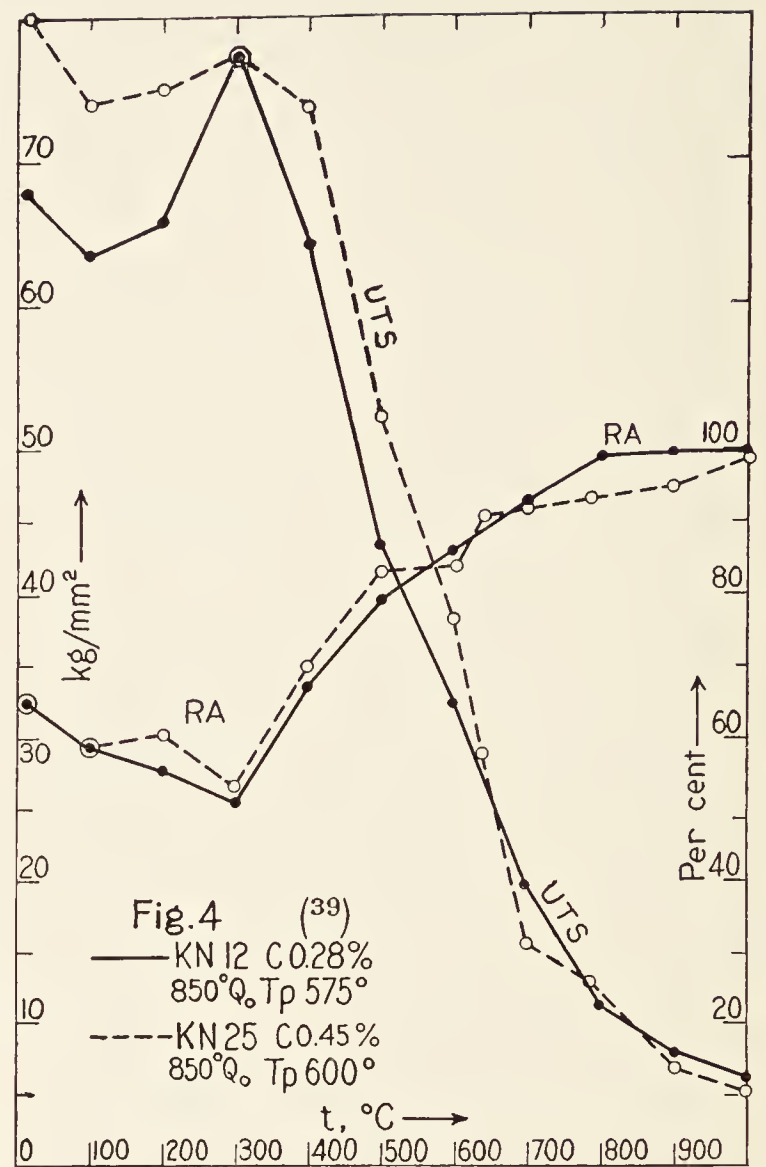




TABLE 2, PART I.—CARBON STEELS (TENSILE PROPERTIES).—  
(Continued)

Key No.	Treatment	UTS	YP	PL	EL	EL	RA	Lit.
16	A 675°/30.....	40.1	21.0	19.7			62	(123)
	A 1150°/30.....	41.7	15.0	11.2			54	
	A 1115°/120.....	40.6	13.8	11.8			55	
	Rolled.....	46.2	27.4	26.3			61	
17	A 900°.....	50.3	25.0			26	39	(67, 89)
	850° Q <sub>w</sub> 600° C <sub>f</sub> .....	57.3	33.4			26	61	
	F { longitudinal.....	57.8	26.7	22.1		27	42	
	transverse.....	54.1	25.7	20.2		18	31	
	radial.....	55.3	27.0	19.6		23.5	36	
18	As cast.....	35.4	24.2			5.5	6	(7, 81)
	A 950°.....	34.0	15.2			16	21	
	900°, { 600°/2h C <sub>a</sub> .....	60.5	38.7	34.6		29	64	
	Q <sub>o</sub> , { 650°/2h Q <sub>w</sub> .....	55.1	37.4	28.4		32	68	
	Tp { 650°/2h C <sub>a</sub> .....	54.1	37.2	29.9		32	69	
19	Rolled.....	53.2	25.5	21.1		31	49	(49, 68,
	N 850°.....	52.7	29.7	27.4		30	53	72, 94,
	A 850°.....	50.6	28.1	24.4		32	50	110)
	900°/60 C <sub>a</sub> .....					29	50	
	760°/60 Q <sub>o</sub> .....	61.4	30.8	23.6				
	Same, { Q <sub>w</sub> .....	54.3	28.7	20.4		35	58	
	650° { C <sub>f</sub> 1°/m.....	52.1	24.4	18.7		34	58	
	/120							
	900°, { Q <sub>w</sub> .....	62.4	36.8	26.7		27	56	
	60 Q <sub>o</sub> , { C <sub>f</sub> 1°/m.....	59.6	32.0	25.2		30	56	
	60 C <sub>f</sub>							
	900°/60 C <sub>f</sub> .....	54.3	23.9	12.6		29	43	
	900° { 600°.....	54.0	32.3	31.1		32	57	
	/30, { 680°.....	49.6	28.5	26.6		39	63	
	C <sub>a</sub> W { 750°.....	48.0	27.8	27.1		40	65	
20	R <sub>h</sub> .....	54.8	32.2	31.6		33.5	58	(128)
21	As cast.....	34.3	24.0			7.5	10	(7)
	A 950°.....	37.4	17.6			19	23	
22	R <sub>h</sub> .....	65.1	30.5	25.6		19f-23d	43	(141)
	A { 350°.....	69.0	33.4	29.5		20f-24d	39	
	750°.....	64.5	32.5	26.6		21f-26d	48	
	850°.....	64.4	35.6	33.7		24f-28d	46	
	1000°.....	65.8	36.1	34.1		22f-27d	48	
	750° Q <sub>w</sub> .....	55.5	35.4	19.7		17.5f-21d	41	
	Same, { 350°.....	65.9	32.5	19.7		20f-24d	44	
	550°.....	64.1	31.8	25.6		20f-25.5d	44	
	Tp { 650°.....	67.4	32.5	28.6		21.5f-27d	53	
	750° Q <sub>o</sub> 80°.....	66.6	33.5	25.6		18f-22d	44	
	Same, { 350°.....	63.7	30.2	25.6		20f-25d	44	
	Tp { 550°.....	62.2	30.4	25.6		22f-26.5d	57	
	850° Q <sub>w</sub> .....	87.9	57.4	13.8		0.3f-0.6d	2.5	
	Same, { 350°.....	169.6		33.3		3f-3.5d	17	
	550°.....	109.6	91.0	65.2		10f-14d	55	
	Tp { 650°.....	82.3	67.2	49.4		13f-19d	59	
	850° Q <sub>o</sub> 80°.....	96.5	68.9	46.3		12f-15d	39	
	Same, { 350°.....	97.5	65.0	45.3		12f-14d	46	
	Tp { 550°.....	88.5	61.0	51.1		13f-17d	49	
23	Wire 5 mm diam.....	63.1				4.5	12	(88)
	A 800-900°.....	57.3				19	60	
	750° Q <sub>o</sub> .....	107.6				5	37	
	850° Q <sub>o</sub> .....	149.3				0	0	
	950° Q <sub>o</sub> .....	139.0				0	0	
	850° { Q <sub>w</sub> .....	80.0				0	0	
	950°	56.5				0	0	
24	N 820°.....	65.4	36.4	34.1		25	47	(67, 72)
	Tangential.....	61.5	31.0	20.2		22	29	
	Longitudinal.....	61.7	29.5			25	38	
	Radial.....	64.6	33.2	18.5		12	21	
25	N 870°.....	69.4	42.5			27	54.5	(18)
	Bars 1½ in. diam. (v. also Figs. 4, 31, 50 and 51)							
27	As received.....	63.5	37.2			21.5	35	(72, 110,
	N.....	68.2	35.9	32.3		23	42	111)
	A 816-819°.....	57.9	33.2			28.5	46	
	816-819° Q <sub>w</sub> .....	141.1				0.5	0	

TABLE 2, PART I.—CARBON STEELS (TENSILE PROPERTIES).—  
(Continued)

Key No.	Treatment	UTS	YP	PL	EL	EL	RA	Lit.	
27	816-819° Q <sub>o</sub> .....	90.1	61.6			19	52		
	Same, { Tp {	375°.....	91.0	61.8		20	52		
		460°.....	87.9	60.0		19	52		
		560°.....	79.6	55.6		24	57		
		650°.....	71.9	52.3		26	61		
	775° Q <sub>w</sub> 650° C <sub>f</sub> .....	68.1	48.3	47.6		23.5	58		
28	N.....	71.2				18.5	31.5	(97, 144)	
	A 5 SWG rod.....	68.4				17	55		
	15 SWG wire.....	141.7				2	20		
	17 SWG wire.....	157.5				1.5	5		
29	As cast.....	28.9	28.9			3	3	(7)	
	A 950°.....	42.0	16.9			20.5	16		
30	A 840°.....	49.0		29.4		5	6	(146)	
32	A 840°.....	55.2		25.4		6	4.5	(46, 66,	
	N 875°.....	69.4	33.7	31.4		25	40	110,	
	790° Q <sub>w</sub> Tp 650°							146)	
	C <sub>a</sub> .....		59.3	56.4		22	57		
	R <sub>h</sub> 5.37 mm diam.	65.5	36.9	26.0	25.0	23	38		
	D <sub>c</sub> {	4.37 mm							
		diam.....	98.5		45.0	52.5	7	19	
		3.60 mm							
		diam.....	111.3		48.0	54.0	6	15	
		3.00 mm							
diam.....		119.5		57.0	61.5	6.5	14		
2.48 mm									
diam.....	133.4		68.5	74.5	6	14			
1.98 mm									
diam.....	142.2		68.0	92.0	6	13			
33	(v. Fig. 32)								
34	As cast.....	33.3	26.4			3	3	(7)	
	A 950°.....	39.8	18.0			13	14		
35	As received.....	83.6	46.4	Test piece 160 mm long		13.5	34	(45)	
	850° Q <sub>o</sub> Tp 710°	77.3	56.8			17	47		
37	As cast.....	29.6	19.6			1.5	2	(7)	
	A 950°.....	25.9	15.5			2	2		
39	As received.....	74.5	39.9	42.4		19	27	(67, 111)	
	N 810°.....	76.5	45.8			22	38		
	A 809°.....	66.5	35.0			25	40		
	809° Q <sub>w</sub> .....	150.5				0	0		
	809 Q <sub>o</sub> .....	106.4	73.5			16.5	40		
	Same, {	375°.....	107.4	74.5			16	43	
		460°.....	101.8	68.2			16	46	
		560°.....	93.1	65.4			20.5	52	
		650°.....	79.4	55.6			24	62	
		Tp {							
40	FW <sub>2</sub> C <sub>a</sub> .....	84.0				19	34.5	(112, 142)	
	A {	0°.....	57.96				3		3
		700°.....	54.5				6		8
		730°.....	54.3				5		4
		760°.....	56.6				6		8
		775°.....	58.8				5		5
		790°.....	59.0				8		13
		820°.....	61.5				7		7
		850°.....	62.1				7		7
		900°.....	62.7				7		7
		1000°.....	63.4				5		7
		Test piece 200 mm X 20 mm diam.							
41	R <sub>h</sub> 15 mm diam.	80.9	49.4	27.4	26.8	17	26	(46)	
	D <sub>c</sub> {	14.3 mm							
		diam.....	97.0		31.0	30.0	3		15
		13.9 mm							
		diam.....	101.4		31.7	31.9	3		7
		13.2 mm							
		diam.....	105.8		39.3	39.0	2		8
		12.7 mm							
		diam.....	111.5		39.0	39.8	2.5		8
11.2 mm									
diam.....	122.0		50.7	49.6	2.5	6			

TABLE 2, PART I.—CARBON STEELS (TENSILE PROPERTIES).—  
(Continued)

Key No.	Treatment	UTS	YP	PL	EL	RA	Lit.
42	Rh.....	77.1	34.4	25.6		13f-15.5d	22 (141)
	Same, { 350°.....	80.4	36.4	31.5		13f-16d	20
	{ 750°.....	73.6	33.6	23.7		16f-19d	27
	{ 850°.....	77.9	41.7	38.6		16f-19d	31
	{ 1000°.....	77.1	44.1	38.1		12f-20d	30
	750° Q <sub>w</sub> .....	79.6	37.4	17.7		14f-16d	26
	Same, { 350°.....	72.9	35.4	15.8		15f-17d	22
	{ 550°.....	74.7	34.4	29.5		16f-19d	27
	{ 650°.....	73.2	34.4	31.5		15f-18d	26
	750° Q <sub>o</sub> 80°.....	74.2	34.4	28.6		17f-21d	30
	Same, { 350°.....	86.0	33.5	29.5		17f-20.5d	30
	{ 550°.....	71.6	33.4	28.5		17f-21d	29
	850° Q <sub>w</sub> Tp { 350°.....	155.3		55.8		0f-0d	0
	{ 550°.....	111.1	94.5	78.8		9f-13d	30
	{ 650°.....	85.8	72.9	63.1		11f-15.5d	33
	850° Q <sub>o</sub> 80°.....	115.2	78.8	55.1		8.5f-10d	35
	Same, { 350°.....	118.1	82.7	55.1		8f-11d	38
	{ 550°.....	106.3	70.9	59.1		11f-16d	44
45	(v. Fig. 24)						
47	As received.....	89.6	46.2			15	21 (111)
	A 800°.....	78.4	32.6			17	24
	800° Q <sub>o</sub> .....	129.1	70.0			2	0
	Same, { 375°.....	125.3	85.0			4	
	{ 460°.....	123.9	80.8			10	34
	{ 560°.....	103.9	74.2			17	43
	{ 650°.....	87.5	63.7			20	57
48	Sandberg Trt.*...	120.2	92.8			14	16 (5)
	C <sub>a</sub> W <sub>2</sub> 850°.....	91.7				13	18
	C <sub>a</sub> .....	90.1				11	10
49	5 SWG rod { R.....	79.5				17	37 (7, 97)
	{ A.....	50.5				26	60
	25 SWG wire.....	82.0				5	
	As cast.....	31.7	29.2			2	2
	A 950°.....	47.7	21.9			6	5
50	Sandberg Trt.*...	127.9	81.6			13	20 (5)
	C <sub>a</sub> W <sub>2</sub> 840°.....	92.8				15	23
	C <sub>a</sub> .....	97.8				Broke off close	
51	Rh 5.3 mm diam.	81.2	52.3	24.5	26.0	19	36 (46, 141)
	{ 4.58 mm diam.....	101.4		38.5	36.0	8	24
	{ 4.22 mm diam.....	109.0		38.5	43.0	7	20
	{ 3.84 mm diam.....	121.0		45.5	44.0	6	20
	{ 3.43 mm diam.....	126.2		48.5	46.5	6	18
	{ 3.03 mm diam.....	128.0		48.0	46.0	6	16
	{ 350°.....	94.8	45.3	38.4		11f-11d	15
	{ 750°.....	87.2	40.5	34.5		12f-15d	21
	{ 850°.....	91.9	45.4	39.5		13f-15d	25
	{ 1000°.....	94.3	48.2	44.2		12f-15d	21
	750° Q <sub>w</sub> .....	91.6	43.3	17.8		12f-13d	17
	Same, { 350°.....	90.2	45.3	27.6		11f-13d	18
	{ 550°.....	87.9	39.3	33.4		13f-15d	30
	{ 650°.....	89.1	40.4	31.5		13f-15d	21
	750° Q <sub>o</sub> 80°.....	89.6	41.4	34.5		12f-14d	19
	Same, { 350°.....	88.5	40.3	31.5		12f-15d	21
	{ 550°.....	89.3	39.3	34.4		13f-15d	19
	850° Q <sub>w</sub> Tp { 550°.....	125.3	106.6	98.7		7f-11d	27
	{ 650°.....	95.6	81.8	69.0		11f-14d	53
	850° Q <sub>o</sub> 80°.....	140.8	82.4	74.8		7f-9d	30
	Same, { 350°.....	140.0	94.6	63.1		9f-12d	50
	{ 550°.....	126.0	86.6	75.5		8f-9d	29
52	N 825°.....	95.6	51.2	32.9		13 <sub>a</sub>	23 (66)
53	As received.....	68.4		36.8		10	(120)
	800°/2 Q.....	70.2		36.1		13	25
	800°/20 Q.....	65.3		35.1		4	3
	800°/60 Q.....	93.2		93.2			

TABLE 2, PART I.—CARBON STEELS (TENSILE PROPERTIES).—  
(Continued)

Key No.	Treatment	UTS	YP	PL	EL	RA	Lit.
54	A 845°.....	70.3	25.2			13 <sub>a</sub>	13 (89, 111, 122)
	800° Q <sub>o</sub> 450° Cf.....	106.7	65.7			12 <sub>a</sub>	26
	Before D <sub>c</sub> .....	97.7	48.8	39.4		15 <sub>a</sub>	22
	D <sub>c</sub> 8.1 %.....	111.8	87.9	34.6		6 <sub>a</sub>	18
	{ 100°.....	113.1	96.0	37.8		5 <sub>a</sub>	17
	{ 200°.....	118.1	105.5	75.6		5 <sub>a</sub>	14
	{ 300°.....	118.1	102.3	77.3		5 <sub>a</sub>	14
	{ 450°.....	110.2	81.8	69.2		9 <sub>a</sub>	17
	{ 650°.....	91.4	56.7	50.3		14 <sub>a</sub>	29
	{ 700°.....	81.8	39.4	28.3		24 <sub>a</sub>	38
	795° Q <sub>w</sub> .....	65.1				0	0
	795° Q <sub>o</sub> .....	129.1	96.9			4	6
	Same, { 375°.....	138.9				12	34
	{ 460°.....	136.1	93.8			14	37
	{ 560°.....	112.7				19	40
	{ 650°.....	90.3	68.2			19	46
56	A 5 SWG rod.....	80.0				17 <sub>a</sub>	46 (97)
	15 SWG wire.....	164.0				1.5 <sub>a</sub>	3
58	N 850°.....	93.5	51.0	36.4		11 <sub>a</sub>	16 (67)
60	790° Cf.....	59.1	23.5	19.7	17.9	25 <sub>a</sub>	37 (110, 141)
	{ 650° C <sub>a</sub>	80.3	47.5	42.4	42.6	23 <sub>a</sub>	40
	{ 450° C <sub>a</sub>	128.5		68.2	71.8	10 <sub>a</sub>	29
	Rh.....	98.1	46.1	34.5		7f-7.5d	8.5
	{ 350°.....	102.3	47.2	43.3		8.5f-9d	10.5
	{ 750°.....	94.2	43.4	31.5		10.5f-13d	15.5
	{ 850°.....	91.8	45.5	40.5		13.5f-15.5d	23.5
	{ 1000°.....	107.6	56.1	48.1		8.5f-8.5d	11
	750° Q <sub>w</sub> .....	99.4	49.2	31.5		6f-10d	12.5
	Same, { 350°.....	96.8	45.3	23.7		10f-11.5d	14.5
	{ 550°.....	100.6	43.3	33.5		10.5f-11.5d	12.5
	{ 650°.....	96.6	51.3	33.5		10.5f-11.5d	13.5
	750° Q <sub>o</sub> 80°.....	98.3	45.3	35.4		10f-11.5d	16
	Same, { 350°.....	92.8	43.7	38.4		11f-12d	15
	{ 550°.....	92.8	43.3	39.3		10f-12d	16
	850° Q <sub>w</sub> .....	96.1		35.5		0f-0d	0
	Same, { 550°.....	132.4	96.3	62.9		6f-9d	15
	{ 650°.....	100.2	84.5	76.6		10f-13d	35
	850° Q <sub>o</sub> .....	146.7	106.2	72.8		6f-8d	25
	Same, { 350°.....	147.8	100.5	71.0		6f-8d	28
	{ 550°.....	135.7	90.5	51.7		6f-8d	13
61	{ 15.0 mm diam.....	103.0	54.5	27.2	27.5	7	8 (46)
	{ 14.3 mm diam.....	116.0		32.3	32.7	1	3
	{ 13.9 mm diam.....	121.0		37.9	36.9	1	3
	{ 13.2 mm diam.....	126.5		38.0	37.5	1	3
	{ 12.7 mm diam.....	131.0		44.2	43.3	0	2.5
62	815° Q <sub>o</sub> { Tp 455°	140.2	79.8			7	8 (38)
	825° Q <sub>o</sub> { Tp 455°	150.0	79.8			6	13
	815° Q <sub>o</sub> , { 585°...	110.1	72.1			7	9
	{ 655°...	89.9	49.2			12	22
	815° Q <sub>w</sub> Tp 700°	74.5	56.3			14	34
63	As cast.....	51.0	35.0			2	2 (7, 65)
	A 950°.....	45.7	29.2			4	2
	875° Q <sub>w</sub> Tp 450°	142.0	106.1			9	23
	875° Q <sub>o</sub> Tp 450°	140.6	118.7			8	20
64	N 815°.....	91.4		38.7		14 <sub>a</sub>	22 (44)
	780°/30 { Tp	80.8		70.3		14.5 <sub>a</sub>	25
	{ Q <sub>w</sub> 538°	98.4		61.2		7 <sub>a</sub>	10
	{ Q <sub>w</sub> 15 min	110.0		64.1		11 <sub>a</sub>	16
	788°/30 { Q <sub>o</sub>						
	788° Q <sub>o</sub> alt†.....	100.5		55.9		8.5 <sub>a</sub>	20
	788° Q <sub>Pb</sub> †.....	92.1		49.4		10 <sub>a</sub>	12.5
	843° Q <sub>Pb</sub> §.....	96.0		50.1		11 <sub>a</sub>	19



TABLE 2, PART I.—CARBON STEELS (TENSILE PROPERTIES).—  
(Continued)

Key No.	Treatment	UTS	YP	PL	EL	El	RA	Lit.
64	843°/30	135.0		84.4		11 <sub>a</sub>	29.5	
	843°/300	139.0		86.5		9.5 <sub>a</sub>	23	
	760°/30	123.3		79.4		11 <sub>a</sub>	40	
	760°/300	135.2		93.8		8 <sub>a</sub>	22.4	
	Following specimens wet ground after treatment							
	780°/30	113.1		96.7		12 <sub>a</sub>	31	
	Q <sub>w</sub> Tp							
	843°/30	116.8		89.7		10 <sub>a</sub>	31	
	Q <sub>w</sub> 15							
	788°/30	125.5		78.6		13 <sub>a</sub>	39	
65	Q <sub>o</sub>							
	788° Q <sub>salt</sub> †	100.9		60.1		14.5 <sub>a</sub>	35.5	
	788° Q <sub>Pb</sub> †	105.5		58.0		15 <sub>a</sub>	37	
	760° 30 Q <sub>o</sub>	110.0		71.0		13.5 <sub>a</sub>	44	
	788° Tp 538°	125.5		78.6		13 <sub>a</sub>	39	
	816° 20 m C <sub>o</sub>	131.9		83.6		11 <sub>a</sub>	30	
	871°	124.9		82.9		12 <sub>a</sub>	30	
	840° { 704°/1 h	82.7		56.3		19	48	
	Q <sub>o</sub> Tp { 704°/5 h	63.3		44.4		33	61	
66	5 SWG rod { R...	98.8				10	15	(97)
	A...	62.6				25	52	
	25 SWG wire....	94.5				5		
	N.....	81.9	42.5	41.0	41.4	8 <sub>a</sub>	11.5	(110, 141)
	790° Q <sub>o</sub> Tp 460°	126.5	91.4	84.4	84.3	9 <sub>a</sub>	15	
	Rh.....	88.6	51.2	35.4		2.5f-2.5d	4	
	A { 350°.....	101.3	53.1	49.2		3.5f-4.5d	4	
	750°.....	95.6	49.3	46.3		10f-10.5d	12.5	
	850°.....	87.9	47.2	40.3		15f-18d	25	
67	1000°.....	103.8	57.7	55.8		4f-4d	4	
	750° Q <sub>w</sub> .....	100.4	53.2	25.6		5f-5d	6	
	Same, { 350°.....	97.7	47.3	29.6		6f-6.5d	5	
	550°.....	98.5	49.2	41.4		5.5f-5.5d	6	
	Tp { 650°.....	98.4	51.2	43.3		8f-10d	8.5	
	750° Q <sub>o</sub> 80°.....	98.3	51.1	45.2		9f-9.5d	11	
	Same, { 350°.....	98.5	49.2	45.3		8f-9d	7.5	
	Tp { 550°.....	98.1	49.2	43.3		8.5f-10d	9.5	
	850° Q <sub>w</sub> { 350°...	125.4		77.8		0f-0d	0	
	Tp { 550°...	141.3	113.8	64.8		6f-6.5d	11	
68	650°...	103.6	82.1	77.3		8f-11d	30	
	850° Q <sub>o</sub> 80°.....	147.1	108.4	78.9		8f-9d	15	
	Same, { 350°.....	143.8	92.6	70.1		6f-8d	20	
	Tp { 550°.....	131.0	85.2	54.3		4f-5d	11.5	
	R 5 SWG rod....	84.7				14	15	(97, 111)
	25 SWG wire....	94.5				6		
	As received.....	106.0	54.2			3		
	A 790°.....	70.0	34.3			24.5	40	
	790° Q <sub>w</sub> .....	116.2				0	2	
69	790° Q <sub>o</sub> .....	141.0	85.7			9	17	
	Same, { 375°.....	142.1	91.7			8	13	
	460°.....	139.5	85.7			8.5	13	
	Tp { 560°.....	120.0	74.2			11.5	20.5	
	650°.....	97.6	61.6			15.5	34	
	Normalized.....	78.7	37.0	34.6		4.5 <sub>h</sub>	4	(37)
	F 900-800° A							
	750°/300,	62.2	30.7	28.3		20.5 <sub>h</sub>	25	
	A <sub>2</sub> 670°/180							
70	F 750-700° A	58.3	26.8	19.7		26.0 <sub>h</sub>	30	
	A <sub>2</sub> 670°/240							
	As cast.....	34.8	34.8			0	0	(7)
	A 950°.....	47.2	26.1			2.5	3.5	
	As received.....	97.3	52.1			2	2	(111)
	A 790°.....	68.6	36.0			15.5	20.5	
	790° Q <sub>w</sub> .....	98.3				1	0	
	790° Q <sub>o</sub> .....	131.9	68.2			2.5	5.5	
71	Same, { 375°.....	110.9	87.5			2.5	5.5	
	460°.....	93.8	86.4			3.5		
	Tp { 560°.....	112.7	71.0			4	5.5	
	650°.....	92.0	59.8			11	17	

TABLE 2, PART I.—CARBON STEELS (TENSILE PROPERTIES).—  
(Continued)

Key No.	Treatment	UTS	YP	PL	EL	El	RA	Lit.
78	5 SWG rod { R...	88.8				4	15	(97)
	A...	65.9				11	15	
	25 SWG wire....	94.5	v. also Fig. 6			7.5		
81	As cast.....	32.0	32.0			0	0	(7)
	A 950°.....	22.2	18.4			0	0	
82	As cast.....	20.7	20.7			0	0	(7)
	A 950°.....	20.2	20.2			0	0	

\* Sandberg treatment consists of cooling the tire at a certain rate through the critical range of temperature, by subjecting it as it slowly revolves, to the blast of a large quantity of moist air.

† 788°/30 Q<sub>salt</sub> 538°/15 C<sub>o</sub>.

‡ 788°/30 Q<sub>Pb</sub> 538°/15 C<sub>o</sub>.

§ 843°/60 Q<sub>Pb</sub> 538°/30 C<sub>o</sub>.

TABLE 2, PART II.—COMPRESSION TESTS ON CARBON STEELS\*  
v. also Figs. 14, 15, 16, and 27

Specimen loaded to failure							Compressive stress† = 157.5 kg/mm² (7)		
Key No.	Treatment	UCS	YPC	PLC	ELC	Lit.	No.	Treat-ment	-100 $\frac{\Delta l}{l_0}$
1	Before D <sub>c</sub> .....		25	20.5		(110, 122)	1	Cast	62.5
	D <sub>c</sub> 14.8 %.....		48	30				A 950°	63.5
3	N.....	22	14.5	13.5	13.5	(128)	7	Cast	62
	Rh.....	37	19.5	19				A 950°	62
4	Rh.....	40.5	25	24.5		(128)	18	Cast	56
19	N 815°.....	41.5	26.5	25.5	26	(110)		A 950°	58.5
20	Rh.....	57	32.5	29		(128)	21	Cast	51.5
27	775° Q <sub>w</sub> 650° Cf..	54	42	39	40.5	(110)		A 950°	56
32	N 845°.....	55.5	36	33.5	34	(110)	29	Cast	52.5
	790° Q <sub>w</sub> 650° C <sub>a</sub> ..	68.5	61.5	59.5	60			A 950°	56.5
53	As cast†.....	85				(7)	34	Cast	50
54	Before D <sub>c</sub> .....		52.5	36		(122)		A 950°	54.5
	D <sub>c</sub> 8.1 %.....		63	33			37	Cast	51
60	790° Cf.....	48.5	21	16	16.5	(110)		A 950°	55
	790° Q <sub>o</sub> Tp { 455° C <sub>a</sub>		None	75	74		49	Cast	47
63	Q <sub>o</sub> Tp { 650° C <sub>a</sub>	68.5	51	45.5	47			A 950°	51.5
	As cast†.....	141				(7)	53	A 950°	45.5
68	N 860°.....	41	37.5	39		(110)	63	A 950°	51
	790° Q <sub>o</sub> 460° C <sub>a</sub> ..	78.5	72	73.5			73	Cast	33
82	As cast†.....	156.5				(7)		A 950°	41
							81	Cast	17
Key No.	Trt.	CS	-100 $\times \frac{\Delta l}{l_0}$	Treatment	CS	-100 $\times \frac{\Delta l}{l_0}$	Lit.		
9	R	35	3	500°/30 C <sub>a</sub>	35	3	(26)		
	R	70	20	Same	70	21			
	R	105	39	Same.....	105	39.5			
82								A 950°	58.5

\* For analyses v. p. 484.

† Test piece 1.12 in.  $\times$  0.584 in. diam.

TABLE 2, PART III.—TORSION TESTS ON CARBON STEELS

Key No.	Treatment	Dimensions, inches (d = diameter)	USS*	TMR	YPS	PLS	ELS	Twist, degrees (total)	Lit.
1	N.....	2 $\times$ 0.5 d			9.5	9	8.5		(90, 110)
	A.....	12.06 $\times$ 2.95 d			12	8			
3	Rh.....	2 $\times$ $\frac{1}{2}$ d	32 <sub>c</sub>	43	12.5	10			(128)
		5 $\times$ 1.75 d	31 <sub>c</sub>	41.5	13.5	11.5			
4	Rh.....	2 $\times$ $\frac{1}{2}$ d	32.5 <sub>c</sub>	43.5	17	16			(65, 123)
	N 900°.....	1.75 $\times$ $\frac{1}{2}$ d	33 <sub>c</sub>	44	12			1070	
5	N 900°.....	1.75 $\times$ $\frac{1}{2}$ d	36 <sub>c</sub>	48	17.5			913	(65)
	Same { 700° Q <sub>w</sub> ..	1.75 $\times$ $\frac{1}{2}$ d	39 <sub>c</sub>	52	18.5			971	
	760° Q <sub>w</sub> ..	1.75 $\times$ $\frac{1}{2}$ d	41.5 <sub>c</sub>	55.5	15.5			1028	
	820° Q <sub>w</sub> ..	1.75 $\times$ $\frac{1}{2}$ d	42.5 <sub>c</sub>	57	15.5			1050	
6	Sv.....	1.75 $\times$ $\frac{1}{2}$ d	35.5 <sub>c</sub>	47	14			551	(67)
7	Sv.....	1.75 $\times$ $\frac{1}{2}$ d	40	53.5	18			585	(67)
8	G, Large.....	1.75 $\times$ $\frac{1}{2}$ d	32 <sub>c</sub>	43		9		350	(67)
	Same, A.....	1.75 $\times$ $\frac{1}{2}$ d	33.5 <sub>c</sub>	44.5		17		650	
	G, Small A.....	1.75 $\times$ $\frac{1}{2}$ d	34.5 <sub>c</sub>	46		15.5		700	

TABLE 2, PART III.—TORSION TESTS ON CARBON STEELS.—  
(Continued)

Key No.	Treatment	Dimensions, inches (d = diameter)	USS*	TMR	YPS	PLS	ELS	Twist, degrees (total)	Lit.
13	F Sv $\parallel$ ..... F Sv $\perp$ .....	$1.75 \times \frac{5}{8} d$ $1.75 \times \frac{5}{8} d$	37 <sub>c</sub> 38 <sub>c</sub>	50 51	14.5 15			508 533	(67, 72)
14	A 760° C <sub>a</sub> .....	$3.5 \times 0.33 d$				17			(140)
15	G cast..... G A 925° C <sub>f</sub> ..... G N 925° C <sub>a</sub> ..... N 850°.....		42.5 42 44 43.5 <sub>c</sub>		24.5 18 20 22.5	17 18 17		460 840 1025 548	(65, 95)
19	N 815°..... 845° Q <sub>w</sub> Tp 565° C <sub>a</sub> .....	$2 \times 0.5 d$			16 42.5	14 36	14 36		(110)
20	R <sub>h</sub> .....	$2 \times \frac{5}{8} d$	42 <sub>c</sub>	56	24	22			(128)
24	R..... N 820°..... Sv $\nwarrow$ ..... Sv $\parallel$ ..... Sv $\nearrow$ .....	$1.75 \times \frac{5}{8} d$ $1.75 \times \frac{5}{8} d$ $1.75 \times \frac{5}{8} d$ $1.75 \times \frac{5}{8} d$ $1.75 \times \frac{5}{8} d$	46 <sub>c</sub> 46 <sub>c</sub> 44 <sub>c</sub> 44.5 <sub>c</sub> 45.5 <sub>c</sub>	61.5 61.5 58.5 59.5 60.5	21.5 24.5			518 434 256 346 300	(67, 72)
27	N.....	$1.75 \times \frac{5}{8} d$	47.5 <sub>c</sub>	63.5		26.5		300	(72)
32	N 845°..... 790° Q <sub>w</sub> Tp 650° C <sub>a</sub> .....	$1.75 \times \frac{5}{8} d$ $1.75 \times \frac{5}{8} d$			24 None	21 36.5	21 37.5		(110)
39	R..... N 810°.....	$1.75 \times \frac{5}{8} d$ $1.75 \times \frac{5}{8} d$	58.5 <sub>c</sub> 52.5 <sub>c</sub>	78.5 70	27.5 26			182 320	(67)
58	N 850°.....	$1.75 \times \frac{5}{8} d$	56 <sub>c</sub>	75.5	29.5			184	(67)
60	790° C <sub>f</sub> ..... 790° { 455° } C <sub>a</sub> { Q <sub>o</sub> Tp { 650° } C <sub>a</sub> {	$2 \times 0.5 d$ $2 \times 0.5 d$ $2 \times 0.5 d$			16 None None	11 53 29.5	12 54.5 29.5		(110)
68	N 860°..... 790° Q <sub>o</sub> W <sub>2</sub> 460° C <sub>f</sub> .....	$2 \times 0.5 d$			28 None	25.5 56.5	25.5 58		(110)
70	A 760° C <sub>f</sub> .....	$3.5 \times 0.33 d$				27			(140)

\* Subscript c, Calculated on assumption of uniform stress throughout cross-section.

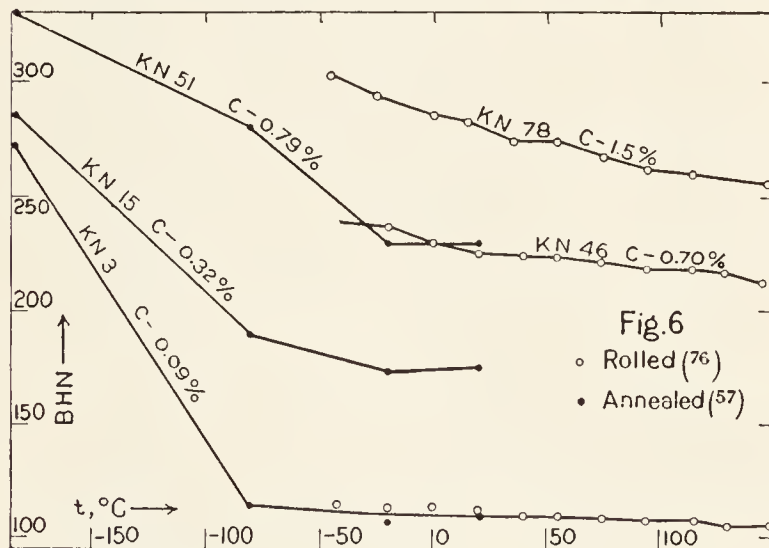


TABLE 2, PART IV.—HARDNESS OF CARBON STEELS\*

Key No.	Treatment	BHN†	ScH	Lit.
1	Before D <sub>c</sub> ..... D <sub>c</sub> 14.8%..... H <sub>wk</sub> 71 kg/mm..... Normalized..... (1½ in. diam.) W 920° { Q <sub>w</sub> Q <sub>o</sub>	105 178 149 69-121 167 137	37	(18, 62, 110, 118, 122)
2	As received (v. also Fig. 53)	120†	21	(46)
3	R } (v. also Fig. 6)..... A }	112 110		(57, 76)
4	N 900°.....	95	21	(65)

TABLE 2, PART IV.—HARDNESS OF CARBON STEELS.\*—(Continued)

Key No.	Treatment	BHN†	ScH	Lit.
5	900° Q <sub>o</sub> ..... Same, Tp 600°..... 866° Q <sub>w</sub> ..... A 866°..... N 900°..... Same, Tp { 700° 760° } Q <sub>w</sub> ... { 820° }	143-156 156 170 107 122 125 146 143	(v. also Figs. 41, 52) 20 22 25 24	(18, 65, 111)
6	As received..... N 920°..... 920° Q <sub>w</sub> ..... Same, Tp 760° Q <sub>w</sub> ..... 920° Q <sub>o</sub> .....	96-144† 137 223 183 170	22‡	(14, 18, 67, 139)
7	As received..... A 858°..... 858° Q <sub>w</sub> .....	118-121† 111 228	(v. also Fig. 41)	(67, 111)
8	Large casting..... Same, A..... Small casting, A.....	116 118 127		(67)
12	Rolled..... A 850°..... N 900°.....	158 150 159	(v. also Fig. 41)	(18, 114)
13	N 870° } 870° Q <sub>w</sub> } 1½ in. diam. { 870° Q <sub>o</sub> }	143 196 179		(18, 67)
	F Sv $\parallel$ ..... F Sv $\perp$ .....	128 109	20-21 19-20	
14	As received..... A 836-900°..... 836° Q <sub>w</sub> ..... 836° Q <sub>o</sub> ..... 900° Q <sub>o</sub> 650°/120... { Q <sub>w</sub> C <sub>f</sub> § 1020° Q <sub>o</sub> 650° Q <sub>w</sub> ..... { Q <sub>w</sub> C <sub>f</sub> § 1250° Q <sub>o</sub> 650°/120... { Q <sub>w</sub> C <sub>f</sub> §	144 134 255 207 169 161 161 174 157	(v. also Fig. 41)	(49, 111)
15	As cast..... A 925° C <sub>f</sub> ..... N 925° C <sub>a</sub> ..... N 850°..... Sv.....	141 143 163 156 163	(v. also Fig. 6) 27	(57, 65, 95)
16	A (v. Fig. 41).....	161		(103)
17	F Sv $\parallel$ ..... F Sv $\perp$ ..... F Sv $\nearrow$ .....	147 143 143	27 28 28	(67)
18	900° Q <sub>o</sub> Tp 2 h { 600° C <sub>a</sub> 650° Q <sub>w</sub> 650° C <sub>a</sub>	173 161 158		(81)
19	N 815°..... N 850°..... A 850°..... 900°/60 C <sub>f</sub> ..... 900°/60 C <sub>a</sub> ..... 760°/60 Q <sub>o</sub> ..... Same, Tp { 650°/120 Q <sub>w</sub> .. 650°/120 C <sub>f</sub> § 900° Q <sub>o</sub> , 650°/2 h .. { Q <sub>w</sub> C <sub>f</sub> §	132 156 145 157 180 162 150 192 178		(49, 68, 72, 110)



TABLE 2, PART IV.—HARDNESS OF CARBON STEELS.\*—(Continued)

Key No.	Treatment	BHN†	ScH	Lit.
19	900°/30, C <sub>a</sub> $\left\{ \begin{array}{l} 600^\circ \\ 680^\circ \\ 750^\circ \end{array} \right\}$ C <sub>s</sub> Tp 5 h	134-160 135 137		
24	N 820°..... Sv $\nwarrow$ ..... Sv $\parallel$ ..... Sv $\nearrow$ .....	170 170 179 174	29	(67, 72)
25	N 870° (v. Figs. 42 and 52)	192		(18)
27	As received..... A 816-819°..... 816-819° Q <sub>w</sub> ..... 816-819° Q <sub>o</sub> ..... 775° Q <sub>w</sub> 650° C <sub>f</sub> .....	170 158 655 261 197	(v. also Fig. 42)	(110, 111)
30	R.....	228	36	(62)
32	As received..... N 845°..... 790° Q <sub>w</sub> 650° C <sub>a</sub> .....	179‡ 193 227		(92, 110)
33	v. Fig. 42			
39	R..... N 810°..... A 809°..... 809° Q <sub>w</sub> ..... 809° Q <sub>o</sub> .....	252 223 183 578 311	40 35 27‡ (v. also Fig. 42)	(59, 62, 67, 111, 139)
40	F W <sub>2</sub> C <sub>a</sub> .....	241		(142)
41	v. Fig. 53			
46	R..... A..... 790° Q Tp 420°..... 841° Q Tp 420°..... 887° Q Tp 420°.....	226 174 418 430 437	(v. also Figs. 6, 29)	(76, 103)
47	R..... A 800°.....	240 217	(v. also Fig. 42)	(111)
50	R.....	273	50	(62)
51	As received..... Annealed.....	255‡ 230	(v. also Fig. 42)	(25, 57)
54	Before D <sub>c</sub> ..... D <sub>c</sub> 8.1%.....	268 293	(v. also Fig. 44)	(111, 122)
56	A..... 717° Q <sub>w</sub> .....	181 217	(v. also Fig. 29)	(103)
58	N 850°.....	286	40	(67)
59	N.....	286		(68)
60	790° C <sub>f</sub> ..... 790° Q <sub>o</sub> 650° C <sub>a</sub> ..... 790° Q <sub>o</sub> 450° C <sub>a</sub> .....	162 227 380	23 31 51	(110)
61	v. Fig. 53			
63	875° Q <sub>w</sub> Tp 450°..... 875° Q <sub>o</sub> Tp 450°.....	402 402		(65)
64	N 815°..... $\left\{ \begin{array}{l} 780^\circ/30 \text{ Q}_w \\ 843^\circ/30 \text{ Q}_w \\ 788^\circ/30 \text{ Q}_o \end{array} \right\}$ Tp 538°/15 788° Q <sub>salt</sub> ¶..... 788° Q <sub>Pb</sub> **..... 843° Q <sub>Pb</sub> ††..... $\left\{ \begin{array}{l} 843^\circ/30 \\ 843^\circ/300 \\ 760^\circ/30 \end{array} \right\}$ Q <sub>o</sub> Tp 538°.. 760°/300	217 258 290 321 286 233 263 376 421 313 387	32 42 46 48 40 34 34 53 58 43 58	(44)

TABLE 2, PART IV.—HARDNESS OF CARBON STEELS.\*—(Continued)

Key No.	Treatment	BHN†	ScH	Lit.
64	780°/30 Q <sub>w</sub> ..... 843°/30 Q <sub>w</sub> ..... 788°/30 Q <sub>o</sub> ..... 788° Q <sub>salt</sub> ¶..... 788° Q <sub>Pb</sub> ..... 760°..... 788° 30 min Q <sub>o</sub> Tp..... 816° 538°/20 C <sub>o</sub> ..... 871°.....	340 340 329 291 266 288 329 364 350	54 48 48 41 37 43 48 52 48	
Last 9 samples wet ground after treatment (v. also Fig. 43)				
65	800° Q <sub>w</sub> .....	600		(120)
66	As received.....	277‡		(92)
67	A (v. Fig. 29).....	176		(103)
68	N..... 790° Q <sub>o</sub> 460° C <sub>a</sub> .....	224 369	31 45	(110)
69	As received..... A 790°..... 790° Q <sub>w</sub> ..... 790° Q <sub>o</sub> .....	288 196 555 402		(111)
72	N..... F 900-800° A ††..... F 750-700° A §§.....	286 189 179		(37)
76	As received..... A 790°..... 790° Q <sub>w</sub> .....	321 202 460	(v. also Fig. 44)	(25, 111)
78	R (v. Fig. 6).....	285		(76)

\* For analyses v. p. 484.

† 10 mm ball; 3000 kg load.

‡ Ludwik cone hardness (90° cone, 3000 kg load): specimens as received.

Key No.	2	6 <sub>a</sub>	6 <sub>b</sub>	7	32	51	66	(92)
LCH	130	101	131	140	195	290	330	

a, Calculated from diameter of impression. b, Calculated from depth.

§ Cf 1°/m.

¶ Turner Scratch Test: No. 6 (as received) = 21; No. 39 (A 809°) = 24 (139)

‡ 788°/30 Q<sub>salt</sub> 538°/15 C<sub>o</sub>.\*\* 788°/30 Q<sub>Pb</sub> 538°/15 C<sub>o</sub>.†† 843°/30 Q<sub>Pb</sub> 538°/30 C<sub>o</sub>.

‡‡ A 750°/5 h 670°/3 h.

§§ A 670°/4 h.

TABLE 2, PART V.—IMPACT STRENGTH OF CARBON STEELS\*

Key No.	Treatment	IS (Izod)	IS (other methods)	Lit.
1	N..... 920° Q <sub>w</sub> †..... 920° Q <sub>o</sub> †.....	3.9 7.0 12.4	$\left\{ \begin{array}{l} 16.6_v \\ 2.7_z \end{array} \right\}$	(18, 68, 110, 118)
2	As received.....	6.9	$\left\{ \begin{array}{l} 2.9_w \\ 23_y \end{array} \right\}$	(64)
3	A.....		8.5 <sub>w</sub>	(33)
4	N 900°.....	11.2		(65)
5	(v. Figs. 47 and 52) N 900°..... 900° Q <sub>w</sub> †..... 900° Q <sub>o</sub> †..... Same, Tp 600°.....	 11.6 10.4 13.0 13.3	 IS <sub>v</sub> 17.0 21.5 18.0 17.5	(18, 65)

TABLE 2, PART V.—IMPACT STRENGTH OF CARBON STEELS.\*—  
(Continued)

Key No.	Treatment	IS (Izod)	IS (other methods)	Lit.
6	As received.....	4.8	$IS_v$	(67, 89)
	N 920°†.....	11.1	14.3	
	920° $Q_w$ †.....	3.3	4.4	
	Same, Tp 760° $Q_w$ .....	5.9	5.7	
	920° $Q_o$ †.....	12.7	16.3	
	<i>v. also</i> Fig. 17		$IS_w$	
	A 925°.....		8.5†	
	900° $Q_o$ 760°, $Q_o$ , Tp 260° $C_a$ .....		123.5†	
7	As received.....	3.5		(67)
8	Castings (large).....	0.9		(67)
	Same, A.....	2.9		
	Small, A.....	2.6	1.2	
12	( <i>v. also</i> Fig. 47)		$IS_v$	(18)
	N 900°†.....	6.3	6	
	900° $Q_w$ †.....	1.8	1.9	
	900° $Q_o$ †.....	4.3	3.5	
13	( <i>v. also</i> Fig. 48)			(18, 67)
	N 870°†.....	3.6	3.1	
	870° $Q_w$ †.....	2.2	2.5	
	870° $Q_o$ †.....	2.8	3.2	
	F Sv   .....	2.5	$\begin{cases} 0.8_w \\ 7_y \end{cases}$	
	F Sv ⊥.....	1.8	1.1 <sub>w</sub>	
14			$IS_x$ §	(49)
	900° $C_f$ .....	1.5	4.7	
	900°/1 h $C_a$ , 760°/1 h $Q_o$	5.1	7.4	
	Same, 650°/2 h $\begin{cases} Q_w    \\ C_f \dots \end{cases}$	5.2	12.3	
	900°/1h $Q_o$ , 650°/2h $Q_w$	5.1	9.6	
	Same, but $C_f   $ .....	5.4	9.0	
	1020° $Q_o$ , 650°/2 h $Q_w$	1.7	3.3	
	1250° $Q_o$ , 650°/2 h $\begin{cases} Q_w \\ C_f \end{cases}$	0.8	1.9	
		0.5	1.8	
15	As cast.....	0.8		(33, 65, 95)
	N 925° $C_a$ .....	2.5		
	A 925° $C_f$ .....	1.8		
	N 850°.....	4.5		
	A.....		$IS_w$	
			5.1	
17	A 900° ( <i>v. Fig. 18</i> ).....		4.3	(89)
18	900° $Q_o$ Tp:			(81)
	600°/2 h $C_a$ .....	3.3		
	650°/2 h $Q_w$ .....	4.4		
	650°/2 h $C_s$ .....	4.0		
19	N.....	4.3	$IS_x$ §	(49, 68, 72)
	900°/1 h $C_f$ .....	1.8	4.0	
	900°/1 h $C_a$ , 760°/1 h $Q_o$	3.3	5.9	
	Same, 650°/2 h $\begin{cases} Q_w \dots \\ C_f    \dots \end{cases}$	2.9	6.4	
		3.3	7.0	
	900° $Q_o$ , 650°/2 h $\begin{cases} Q_w \dots \\ C_f    \dots \end{cases}$	2.5	6.9	
		2.1	5.6	
	900°/30 $C_a$ :			
	Tp $\begin{cases} 600^\circ \\ 680^\circ \\ 750^\circ \end{cases}$ 5 h $C_s$ ..	4.3		
		4.7		
24	N 820°.....	3.9	$IS_w$	(67, 72)
	Sv π.....	0.8	0.4	
	Sv   .....	0.5	0.4	
	Sv ↗.....	0.8	0.4	

TABLE 2, PART V.—IMPACT STRENGTH OF CARBON STEELS.\*—  
(Continued)

Key No.	Treatment	IS (Izod)	IS (other methods)	Lit.
25	N 870°†.....	4.3	3.5 <sub>v</sub>	(18)
	<i>v. Figs. 48 and 52</i>			
27	N.....	2.0	$IS_z$	(72, 110)
	775° $Q_w$ 650° $C_f$ .....		3.1	
32	N 845.....		1.8	(110)
	790° $Q_w$ 650° $C_a$ .....		3.0	
33	790° $Q_o$ .....		1.6	(109)
	$\begin{cases} 205^\circ \\ 315^\circ \\ 425^\circ \\ 540^\circ \\ 650^\circ \\ 760^\circ \end{cases} C_a$		1.2	
			2.0	
			1.6	
			3.1	
			4.2	
			2.7	
39	As received.....	0.7		(67)
	N 810°.....	1.1	$IS_w$	
54	A 845°.....		3.3†	(89)
	800° $Q_o$ 450° $C_f$ .....		9.0†	
	<i>v. also</i> Fig. 19			
58	N 850°.....	0.3		(67)
59	N.....	0.3	$IS_z$	(68)
60	790° $C_f$ .....		0.3	(110)
	790° $Q_o$ , Tp $\begin{cases} 650^\circ C_a \dots \\ 455^\circ C_a \dots \end{cases}$		0.5	
63	875° $Q_w$ , 875° $Q_o$	1.5		(65)
	Tp 450°	1.7	$IS_v$	
64	780°/30 $Q_w$ , Tp 538°/15	0.3	0.4	(44)
	788°/30 $Q_o$ , Tp 538°/15	0.3	0.4	
	I¶.....	0.5	0.5	
	II.....	0.4	0.4	
	843°/30	0.4	0.4	
	843°/5 h	0.4	0.5	
	760°/30	0.4	0.4	
	Above samples not wet ground			
	780°/30 $Q_w$ , Tp 538°/15	0.3	0.4	
	788°/30 $Q_o$ , Tp 538°/15	0.3	0.4	
	I¶.....	0.5	0.5	
	II.....	0.4	0.4	
	760°	0.3	0.4	
	816°		0.5	
	843°	0.4	0.4	
	871°	0.4	0.5	
	788° $Q_w$ , Tp $\begin{cases} 538^\circ \dots \\ 649^\circ \dots \\ 704^\circ \dots \\ 760^\circ \dots \end{cases}$	0.3	0.4	
		0.3	0.4	
	788° $Q_o$ , Tp $\begin{cases} 316^\circ \dots \\ 538^\circ \dots \\ 649^\circ \dots \\ 704^\circ \dots \end{cases}$	0.4	0.6	
		0.3	0.5	
		0.3	0.5	
		0.4	0.4	
	843° $Q_o$ , Tp $\begin{cases} 316^\circ \dots \\ 649^\circ \dots \\ 704^\circ \dots \\ 760^\circ \dots \end{cases}$	0.5	0.5	
		0.5	0.6	
		0.6	0.8	
		0.4	0.4	



TABLE 2, PART V.—IMPACT STRENGTH OF CARBON STEELS.\*—  
(Continued)

Key No.	Treatment	IS (Izod)	IS (other methods)	Lit.
64	843° Q <sub>o</sub> , T <sub>p</sub> 704° { 30 m 5 h	0.6	0.4 <sub>v</sub>	
		0.4	0.6 <sub>v</sub>	
	Above samples wet ground after treatment			
68	N 860°.....		0.3 <sub>z</sub>	(110)
	790° Q <sub>o</sub> 460° C <sub>a</sub> .....		0.3 <sub>z</sub>	
72	N.....	0.2		(37)
	F 900–800°, A 750°/5 h, A <sub>2</sub> 670°/3 h.....			
	F 750–700°, A 670°/4 h	0.2		
		0.2		

\* For meaning of subscripts v. p. 396.

† Bars 1½ in. diam.

‡ Test piece 30 mm<sup>2</sup>, diam. of bottom of notch = 4 mm.

§ Tested in the Guillery machine.

|| Cooled at 1° per minute.

¶ I = 788°/30 Q<sub>alt</sub> 538°/15 Q<sub>o</sub>.|| I = 788°/30 Q<sub>Pb</sub> 538°/15 Q<sub>o</sub>.TABLE 3.—MECHANICAL PROPERTIES OF CAST IRON\*†  
v. also Figs. 7, 7a, 8, and 20

Key No.	ScH	UTS	BMR†	Lit.	Key No.	ScH	UTS	BMR†	Lit.
84	52–58	17	28 <sub>l</sub>	(32)	92	56–61	20	43–59 <sub>l</sub>	(32)
85	62	12.5	28.5 <sub>l</sub>	(32)	93		26.5	41 <sub>m</sub>	(137)
86	54–62	18.5	29 <sub>l</sub>	(32)	94	31	23.5	34 <sub>l</sub>	(32)
87		19	39.5 <sub>m</sub>	(135)	95	56–60	18.5	42–56 <sub>l</sub>	(32)
88	40–43	9–19	34 <sub>l</sub>	(32)	96	40–60	14–29	38 <sub>l</sub>	(32)
89	63	26	45 <sub>l</sub>	(32)	97	31–40	22.5	34 <sub>l</sub>	(32)
90	48–53	26§	34.5 <sub>l</sub>	(32)	98	65	26	47 <sub>l</sub>	(32)
91	40–45	20–31	28–50 <sub>l</sub>	(32)	99	50	21	46 <sub>l</sub>	(32)

Key No.	Hardness		Tensile properties			Compression properties		Bending	Lit.
	BHN	ScH	UTS	El	RA	UCS	PLC	BMR†	
100	187	37–50	24§			100¶	50	34–47	(27, 32, 124, 135)
101**			30–46	6 <sub>a</sub> – 2 <sub>a</sub> ††					(63)
102**	101–145		25–41§	15.0 <sub>a</sub> – 4.5 <sub>a</sub> ††		IS <sub>u</sub> = 0.1			(63, 68)
103		57	20.5					41.5 <sub>l</sub>	(32)
104		58	24.5					49 <sub>l</sub>	(32)
105		43	26.5					40 <sub>l</sub>	(32)
106	160–220	38	16–28§	ca. 0	††	63–105		36	(21, 78, 124, 145)
107	192–200		23.5§					35 <sub>m</sub>	(130, 137)
108	203–213	40–50	21	0.2	0.0	Machined Unmachined		32.5 <sub>o</sub>	(32, 135, 139)
	TSH = 36							45 <sub>m</sub>	
109	207–217	33–36	16.5					31	(68, 145)
110	180		22					33.5 <sub>m</sub>	(137)
111	149–207		18			64.5	34.5	33.5 <sub>n</sub>	(21, 124)
112	160–217		21					27–47 <sub>m</sub>	(137)
113	192		22.5					37.5 <sub>m</sub>	(137)
114	131–176		16			68	27	31.5 <sub>n</sub>	(21, 124)
115			19§						(130)
116			27					54 <sub>m</sub>	(135)
117	110–151	30–40	16–21			44–58			(131)
118	105–143	24§§	15	(PL = 7)		61¶	32.5	30 <sub>n</sub>	(124)

\* For analyses v. p. 485. For effect of Mn and Si content on cast iron v. p. 525.

† All specimens "as cast" except where noted.

‡ Meaning of subscripts to values of BMR: l = 1 in. sq., span 12 in.; m = 1¼ in. diam., span 12 in.; n = 10 × 10 × 65 mm, span 30 mm; o = 0.862 in. sq., span 12 in.

§ For high temperature tests, v. Figs. 7, 7a, 8 and 20.

|| BHN = 175.

¶ 16 mm × 16 mm diam.

\*\* No. 101, Trt = A 840–880°; YP = 19–28; No. 102, Trt = A 770–840°, YP = 16–31.5.

†† For both El and RA.

‡‡ Torsion tests: Soft, (BHN = 92), USS = 14.5  
Fine grained (BHN = 150), USS = 24  
Hard fine grained (BHN = 217), USS = 28 } TMR = 24.5 (78).

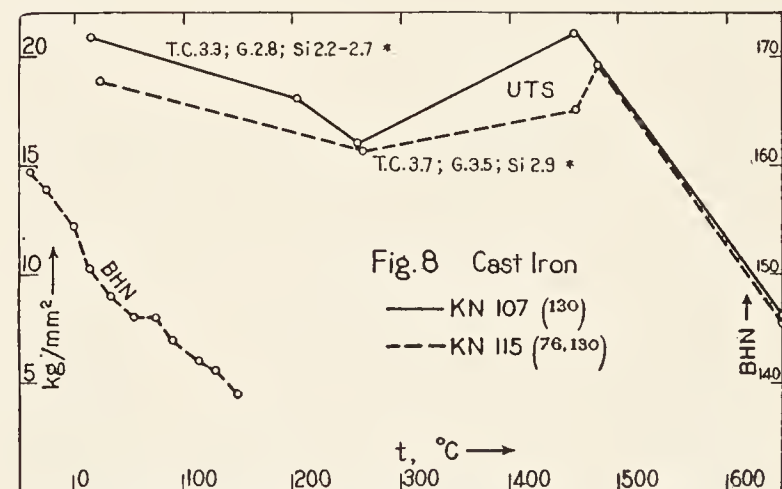
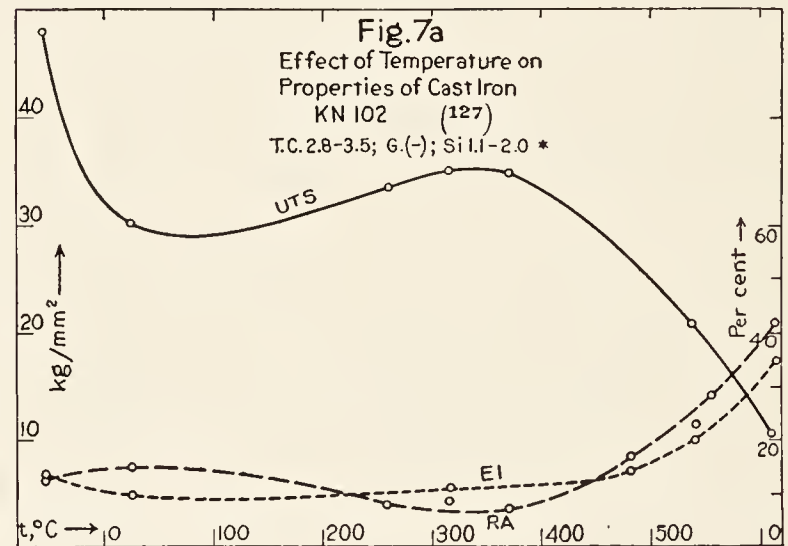
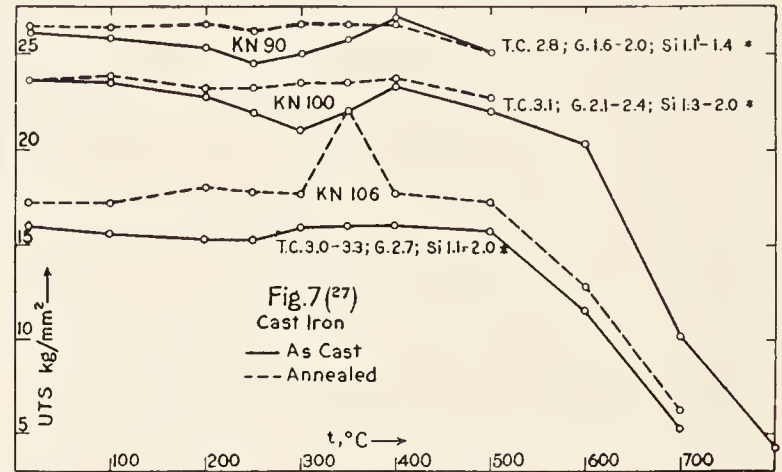
§§ TSH = 21–23.

EFFECT OF ANNEALING ON TENSILE STRENGTH OF CAST IRON (27)

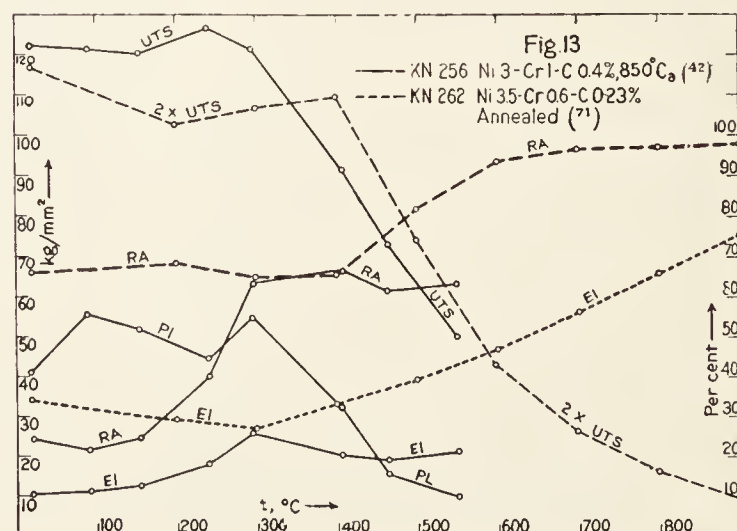
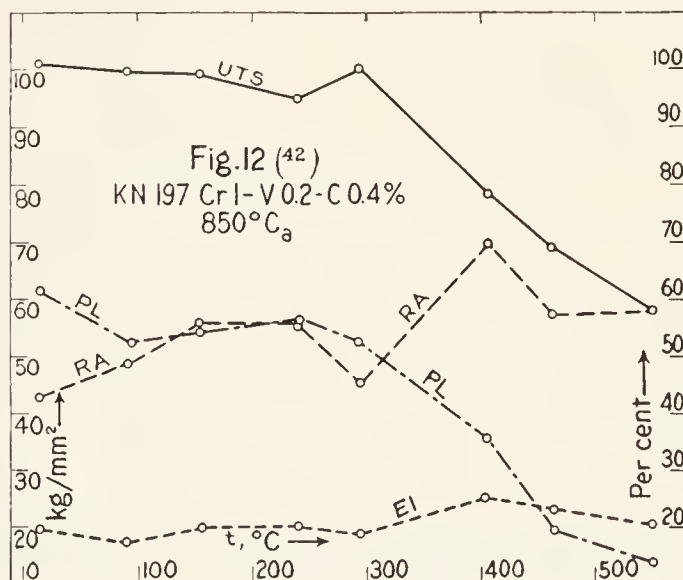
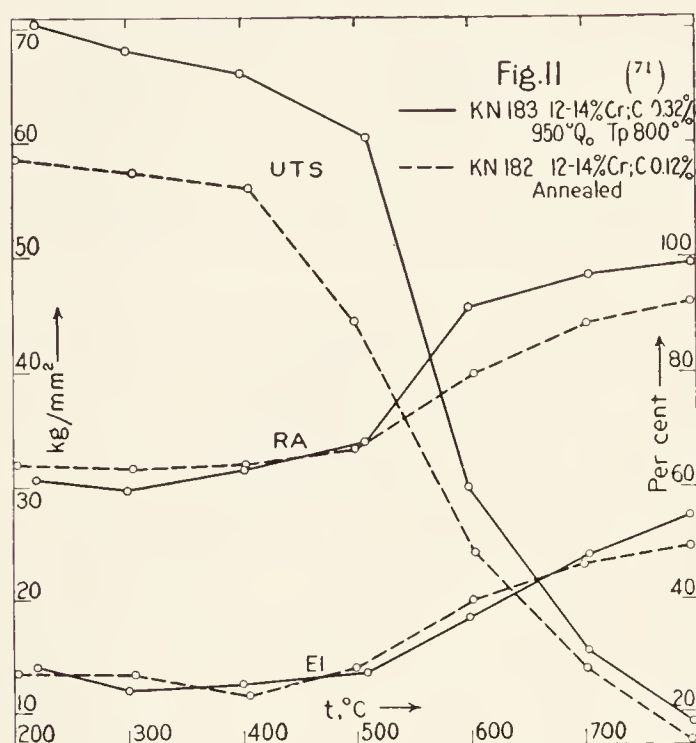
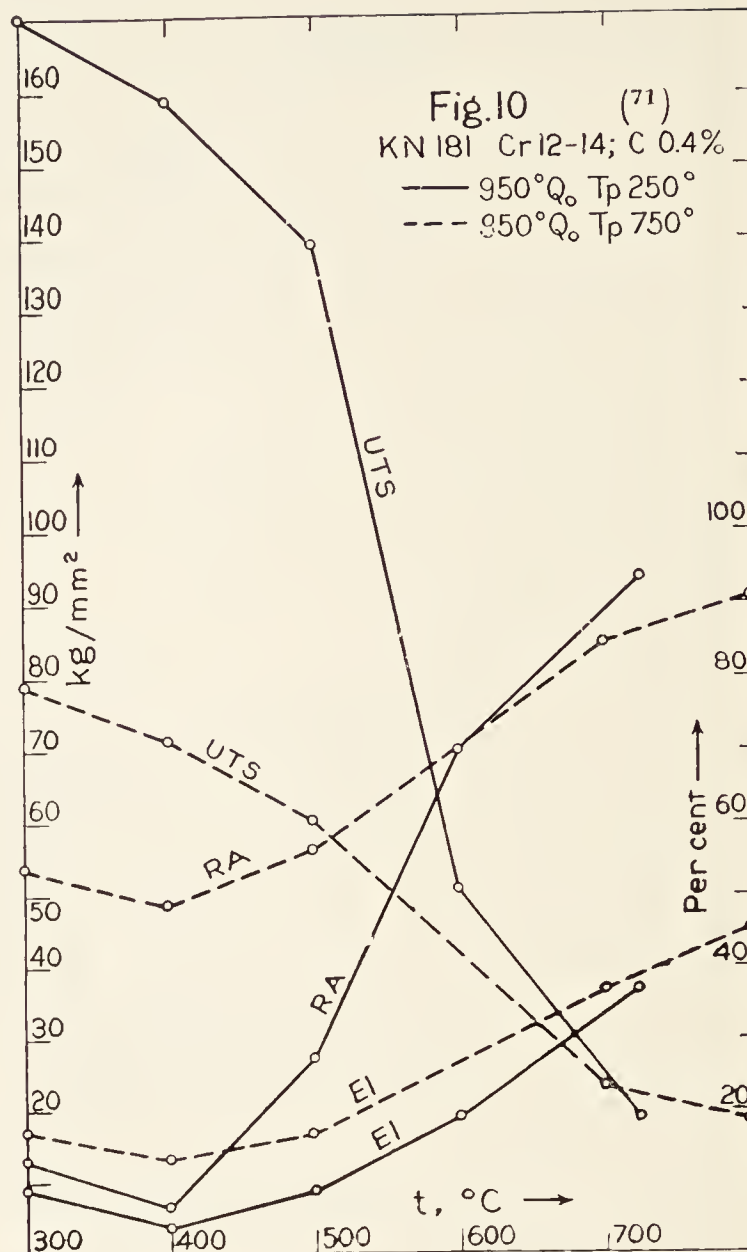
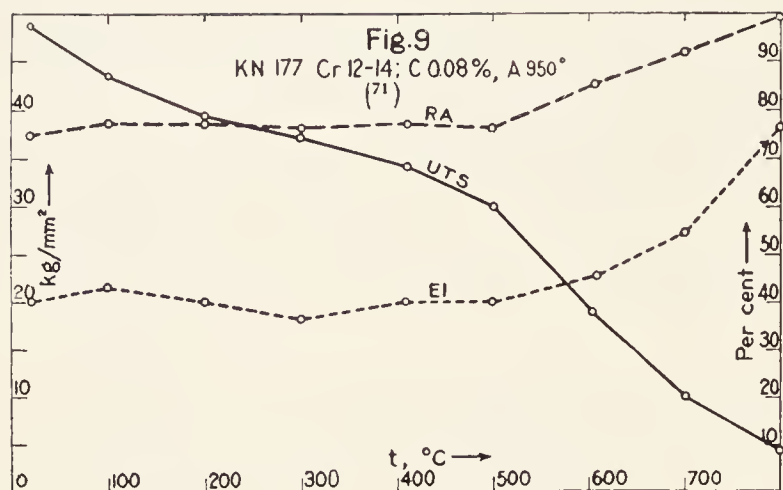
A, t° C	100	200	250	300	350	400	500	600	700
K. No. 90, UTS =	26	25	24.5	25	26	27	25		
K. No. 106, UTS =	16.5	16.5		17		17	17	15	13

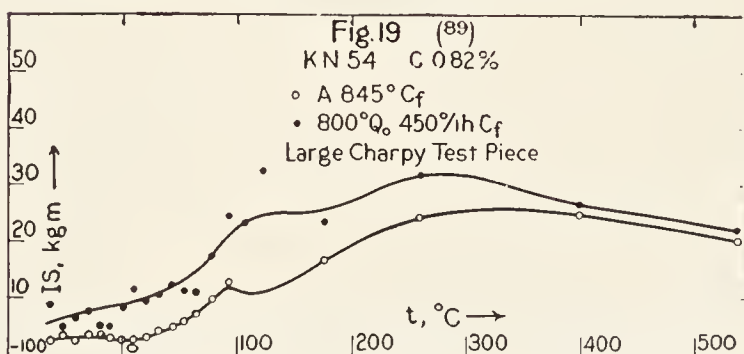
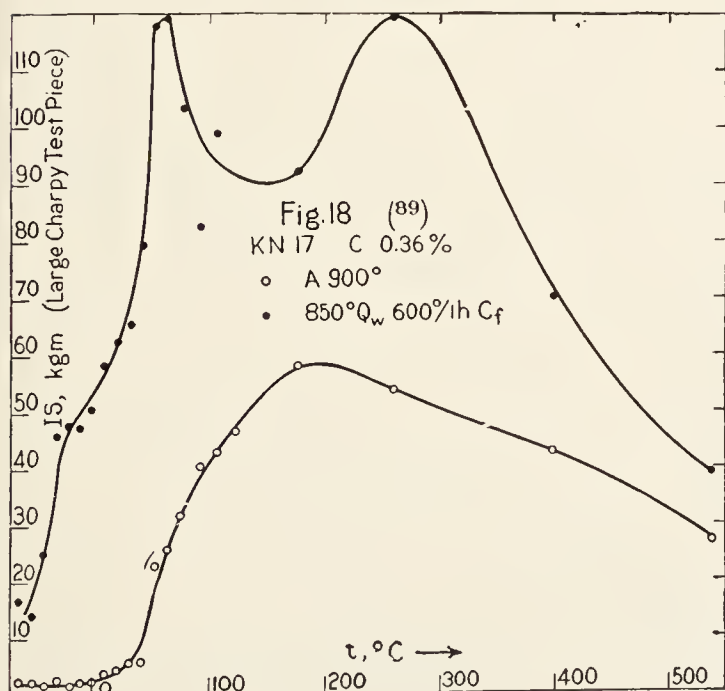
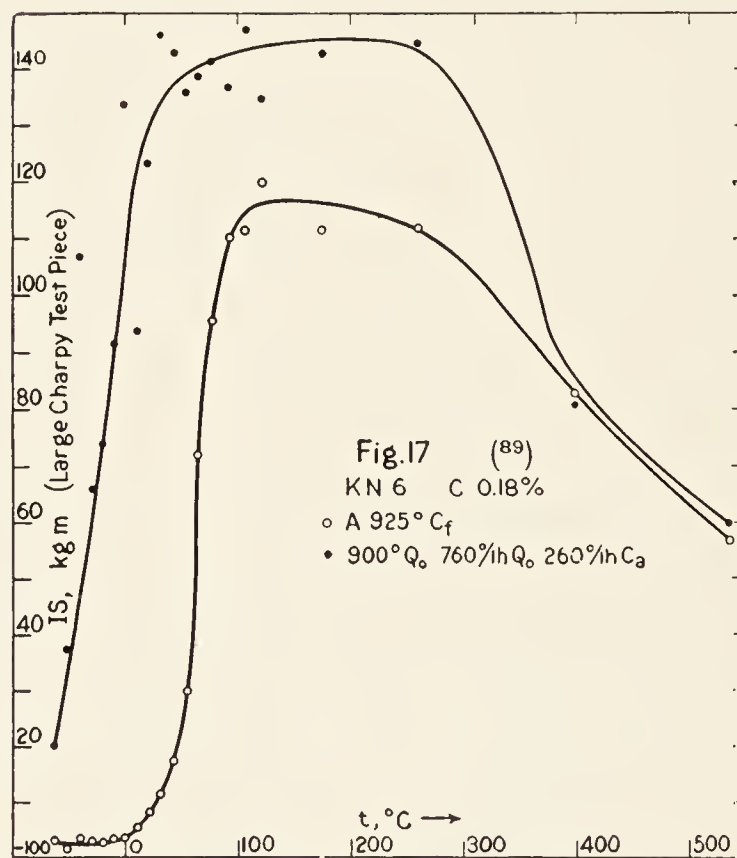
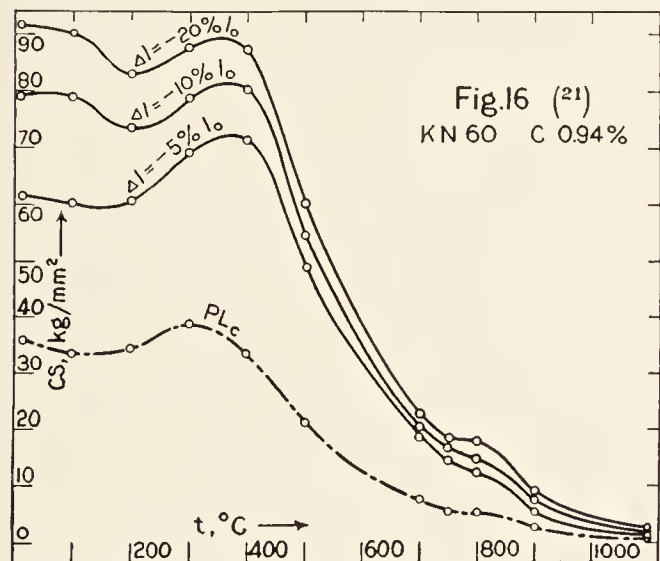
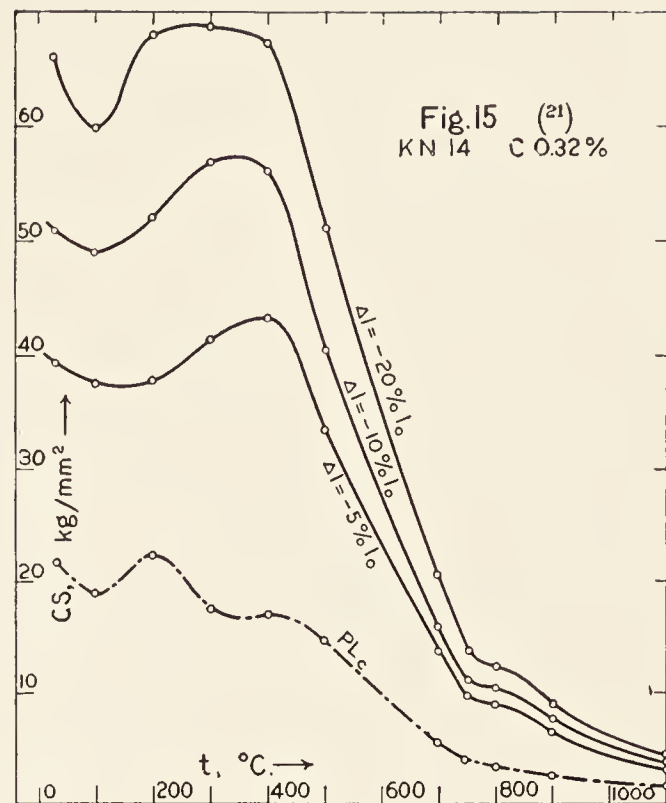
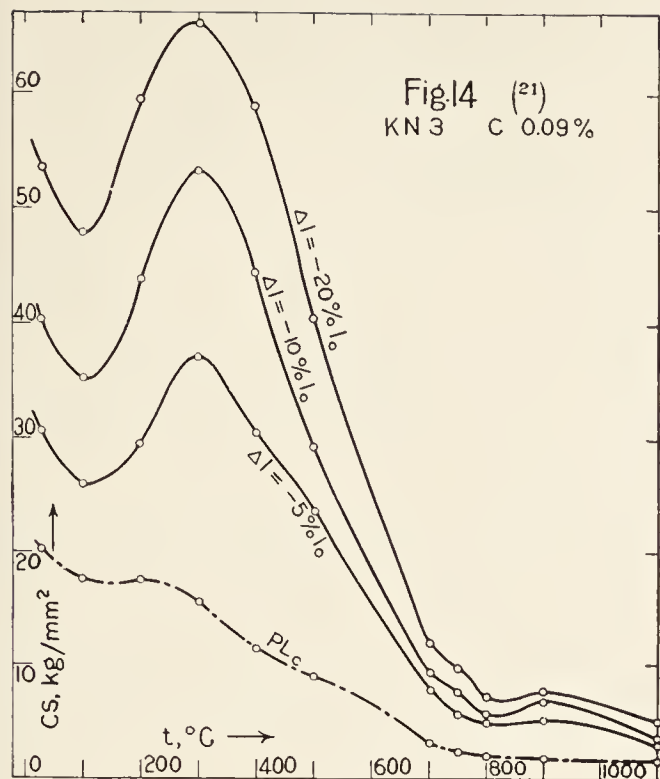
	K. No. 90	K. No. 100	K. No. 106
W 25 times to 450°	UTS = 23.5	21	15
W 25 times to 550°	UTS = 22	20.5	12

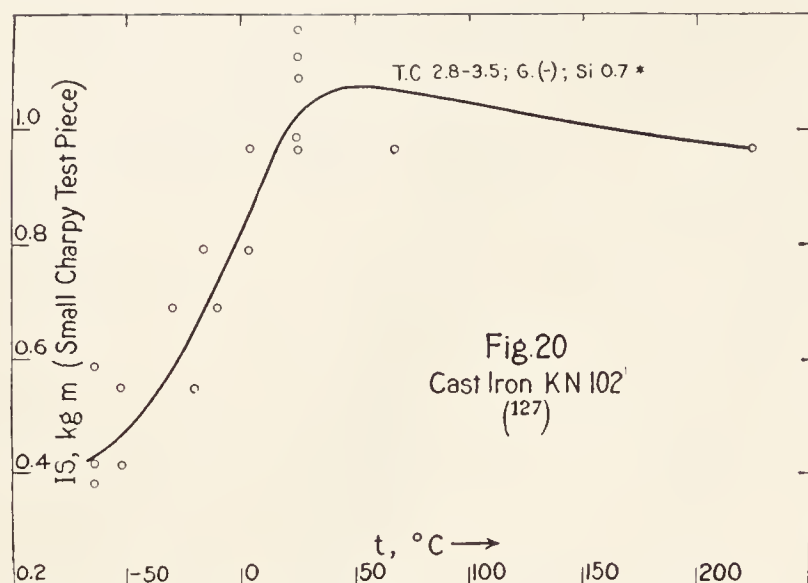


\* T.C. = total carbon; G. = graphite.

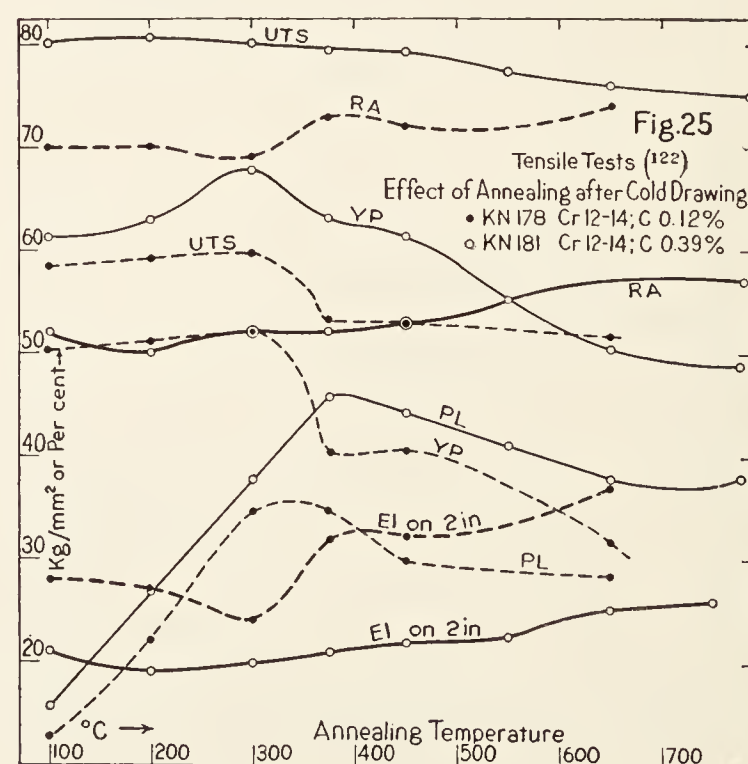
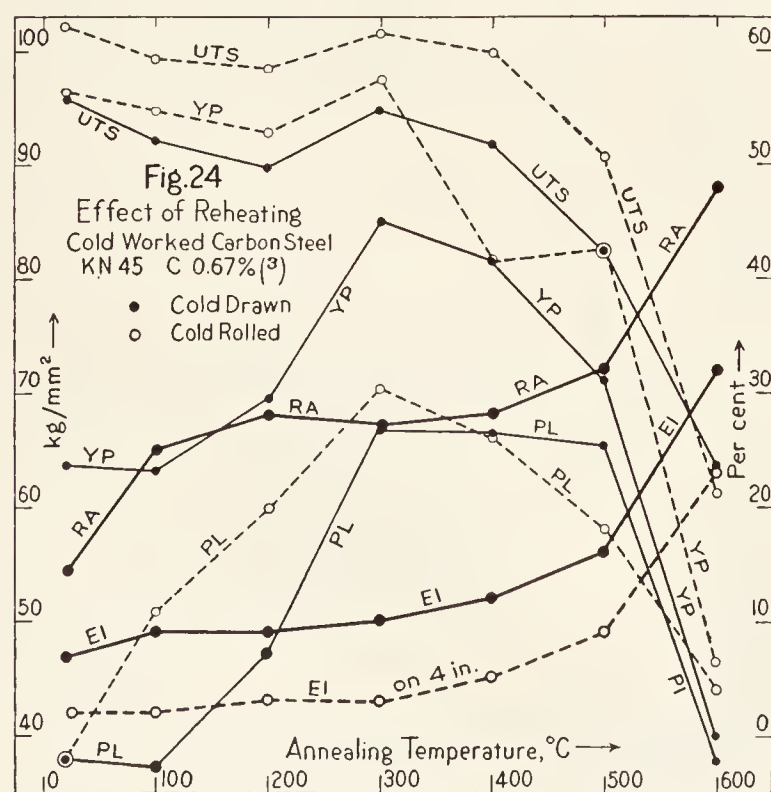
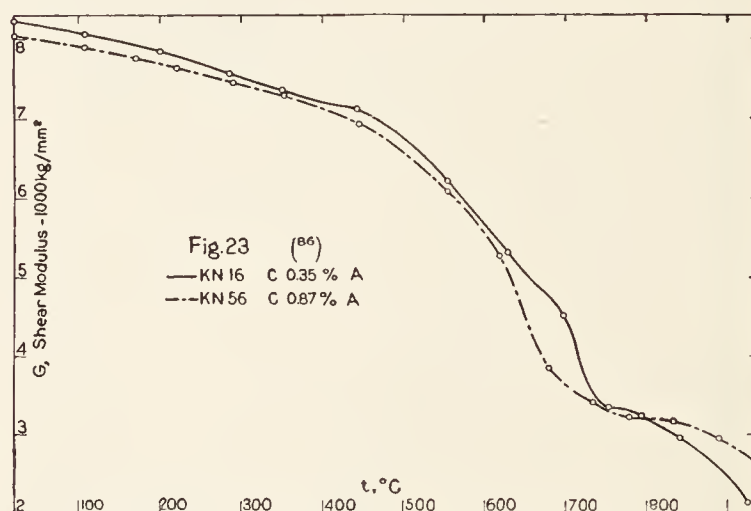
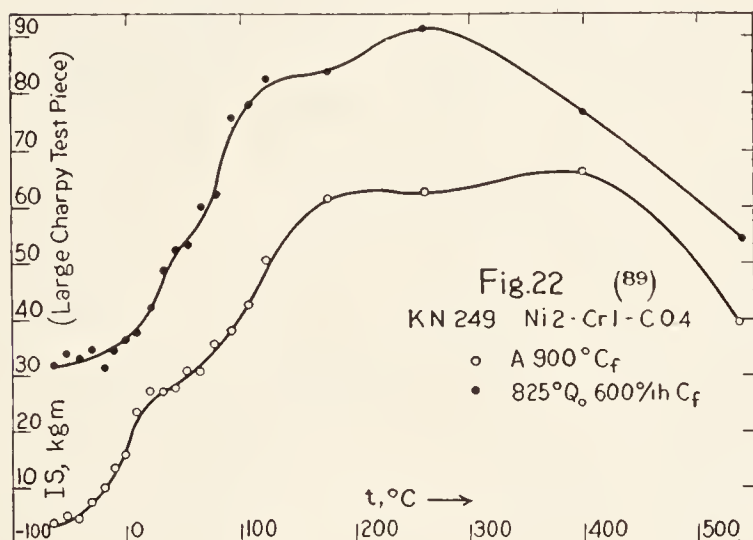
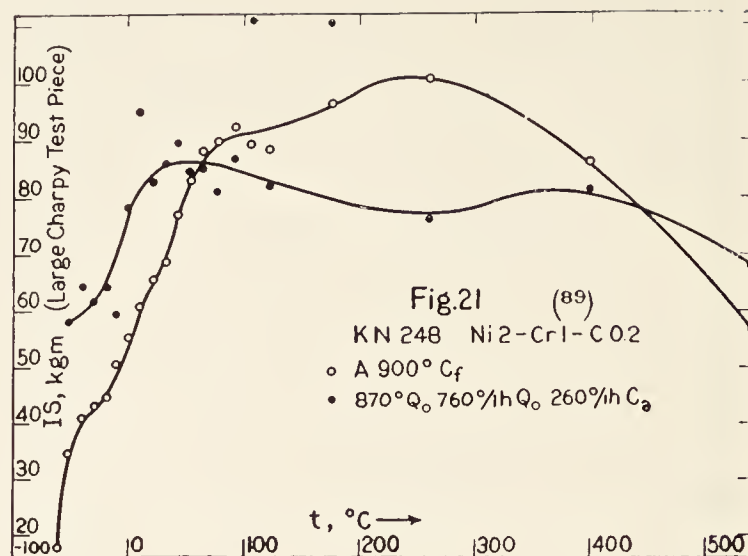




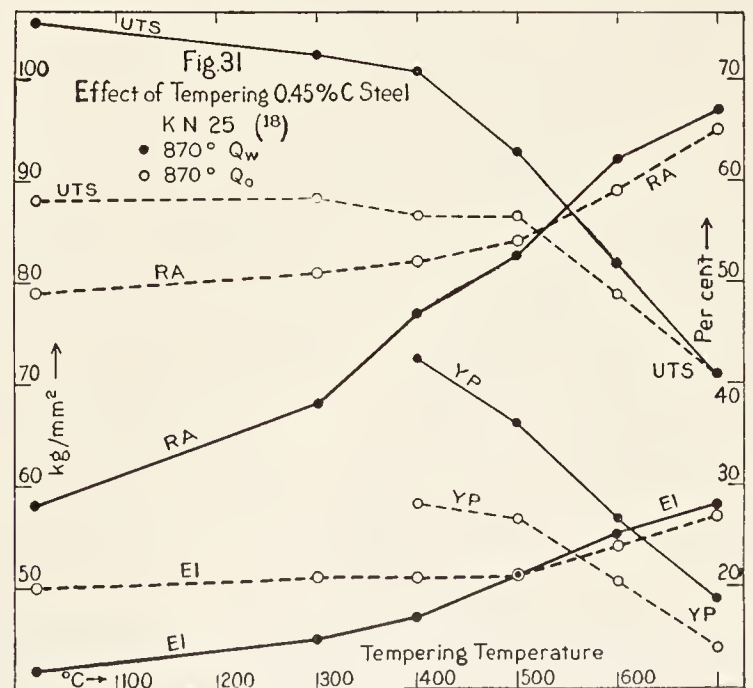
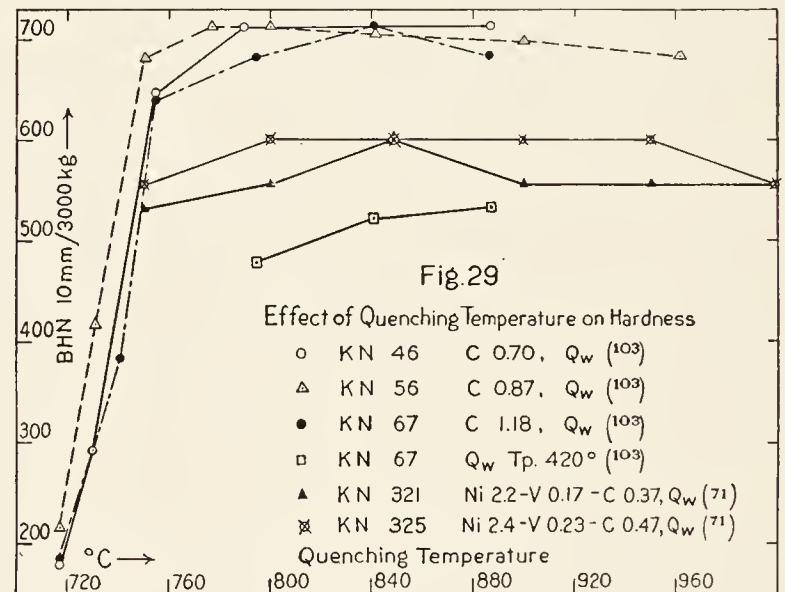
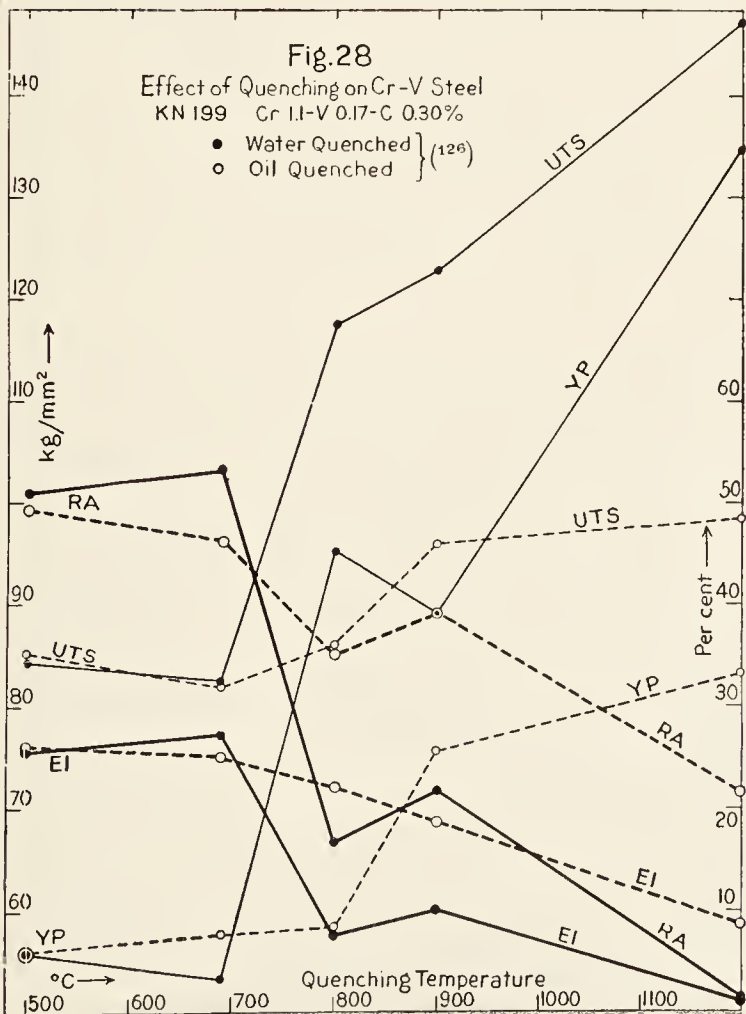
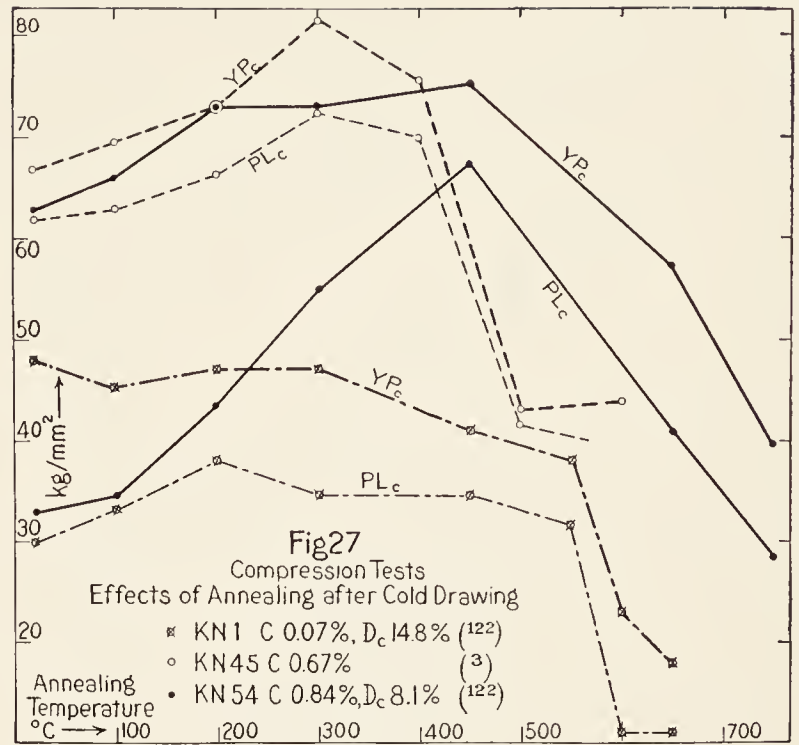
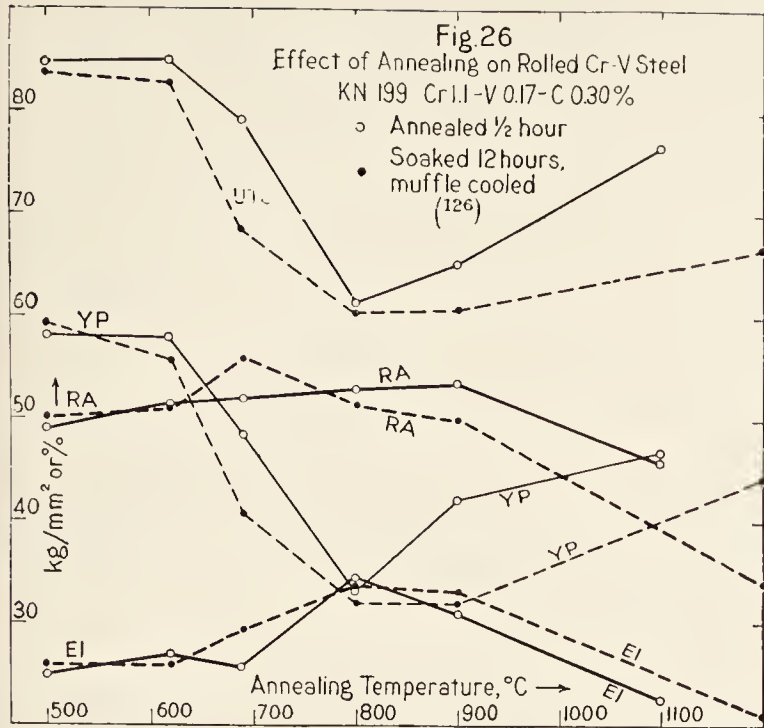


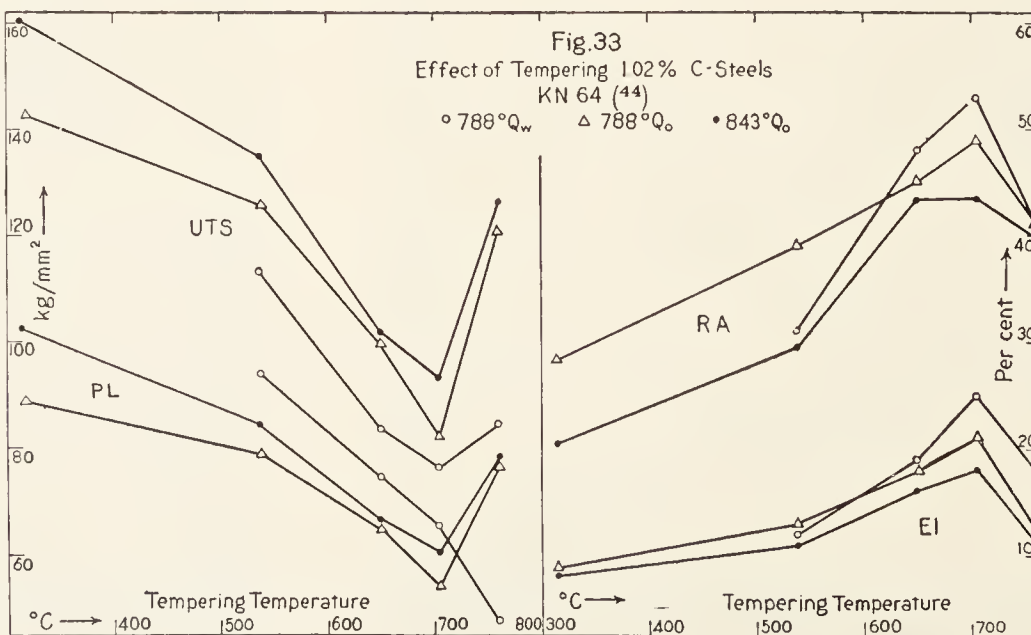
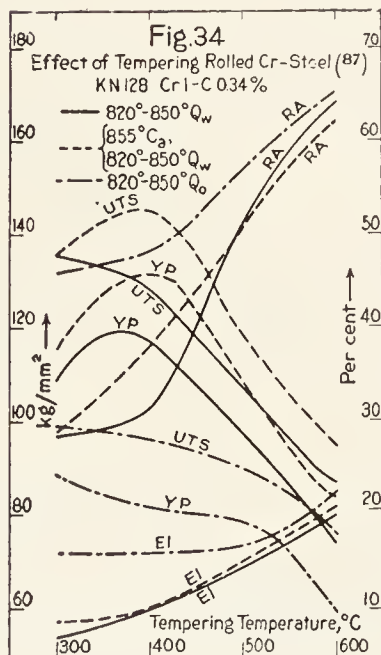
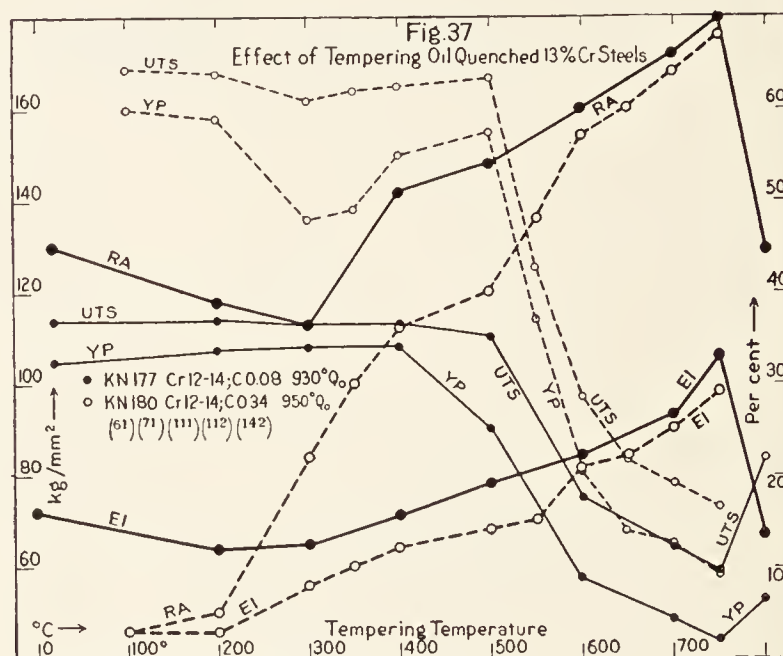
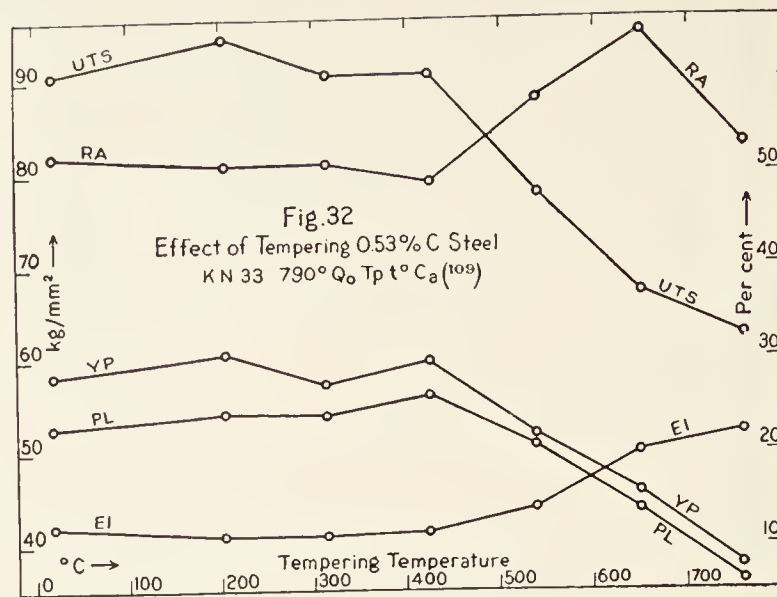
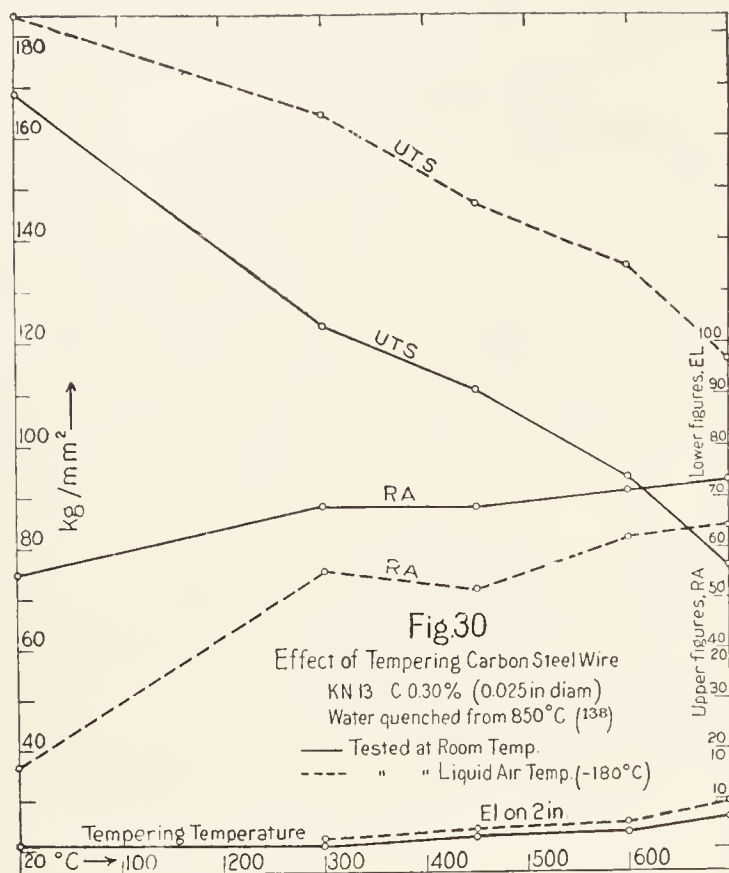


\* T.C. = total carbon; G. = graphite.

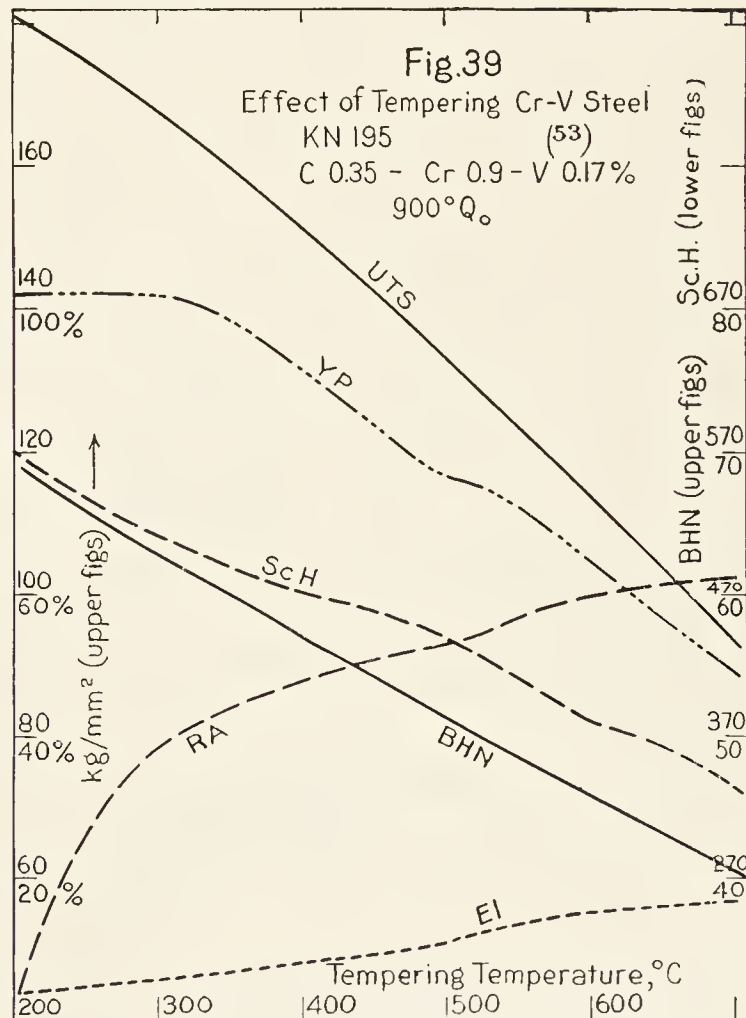
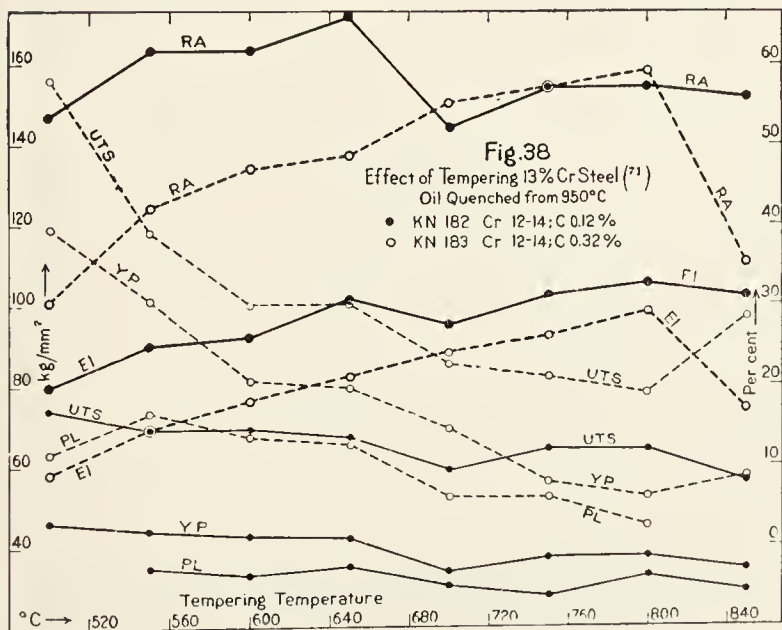
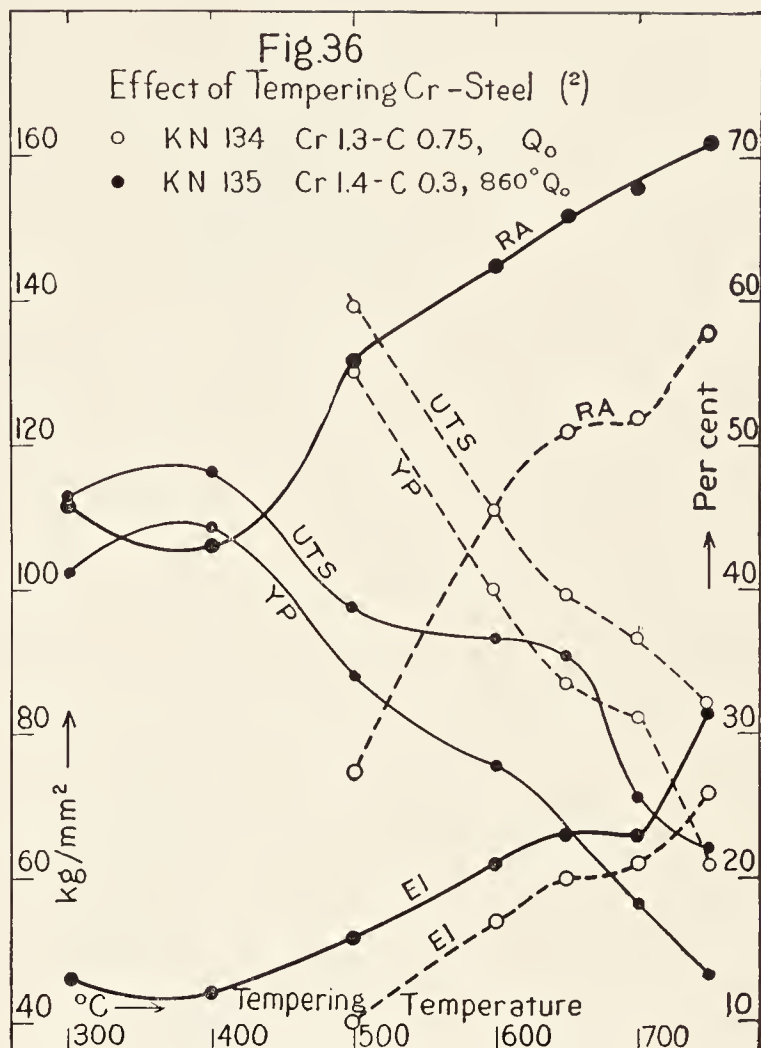
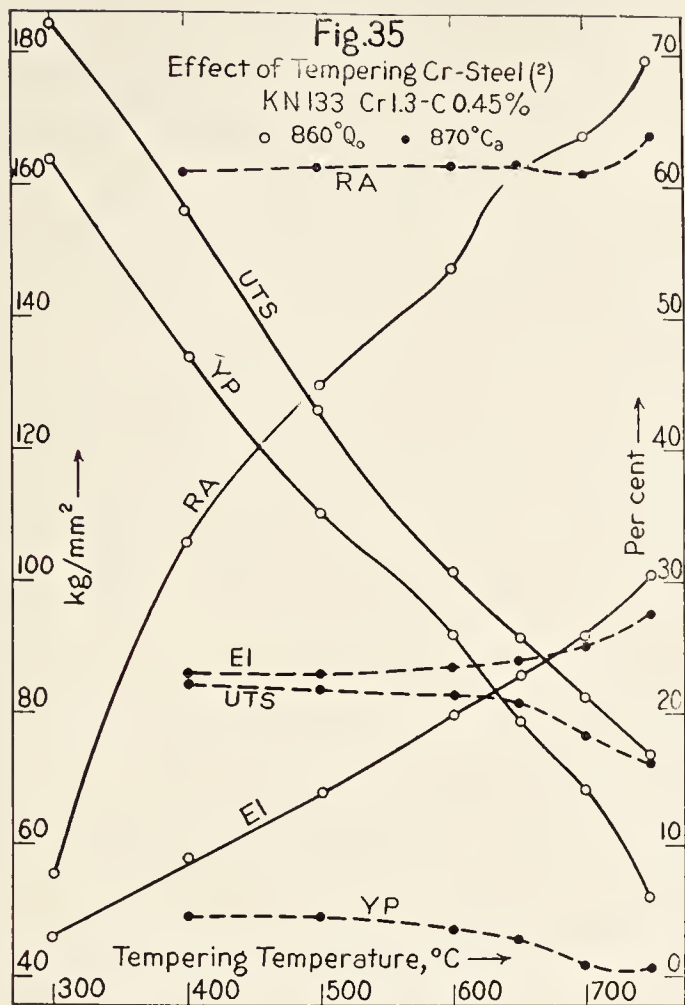


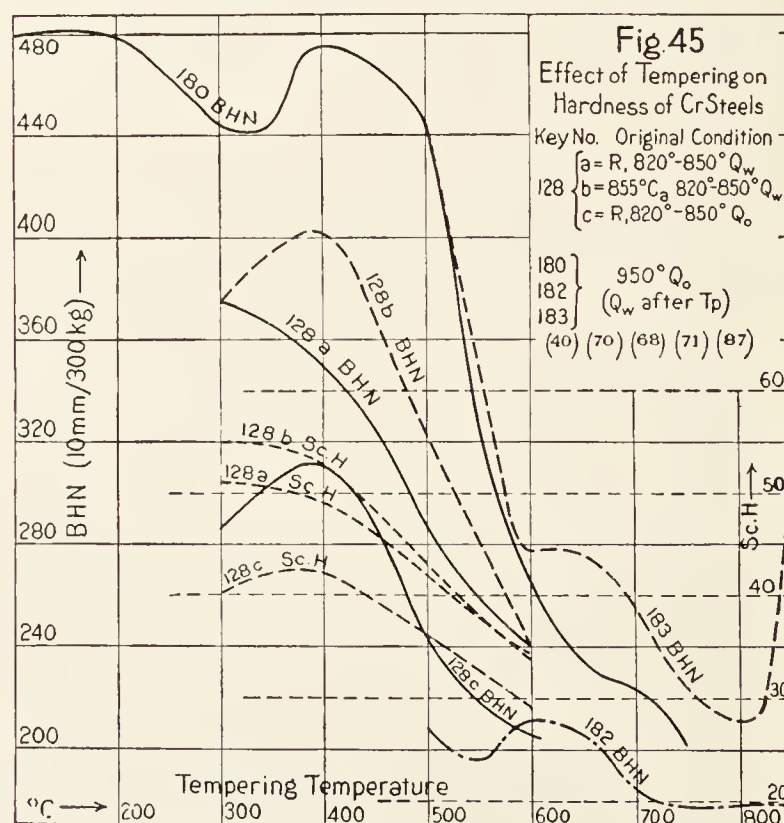
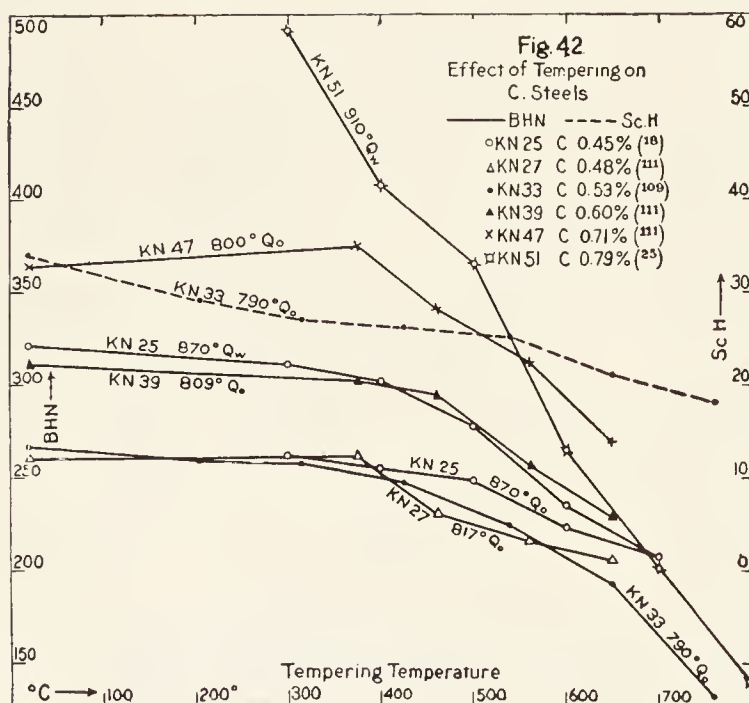
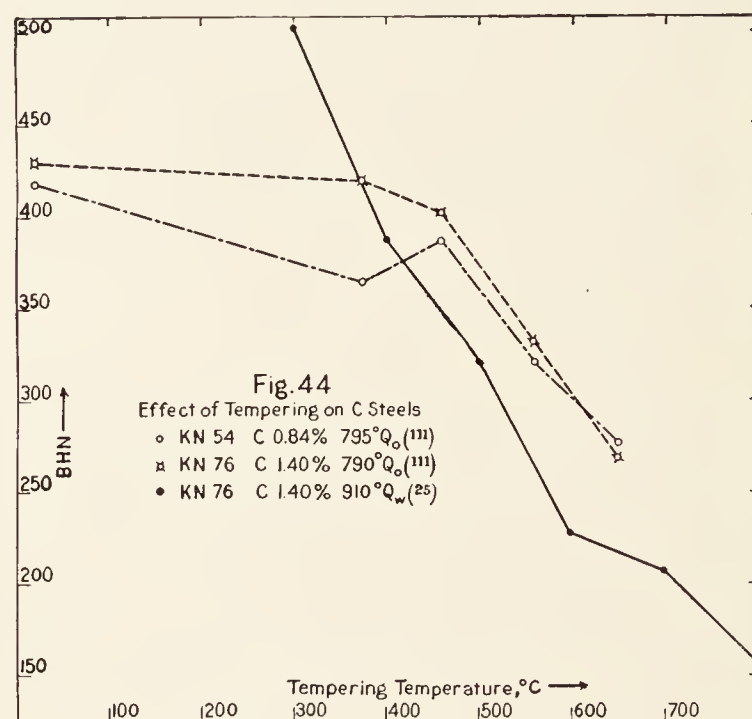
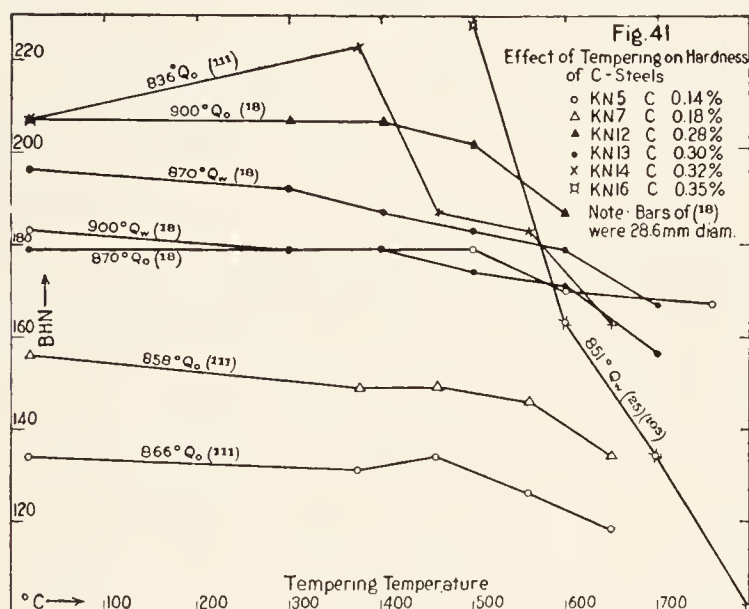
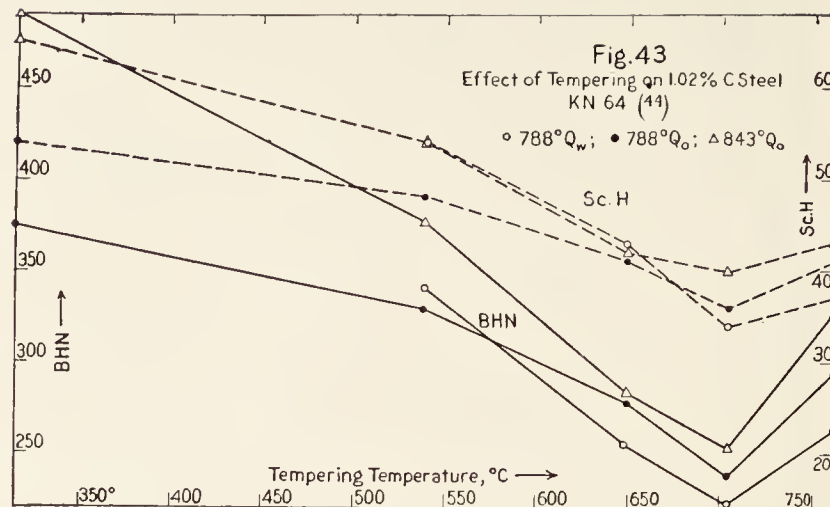
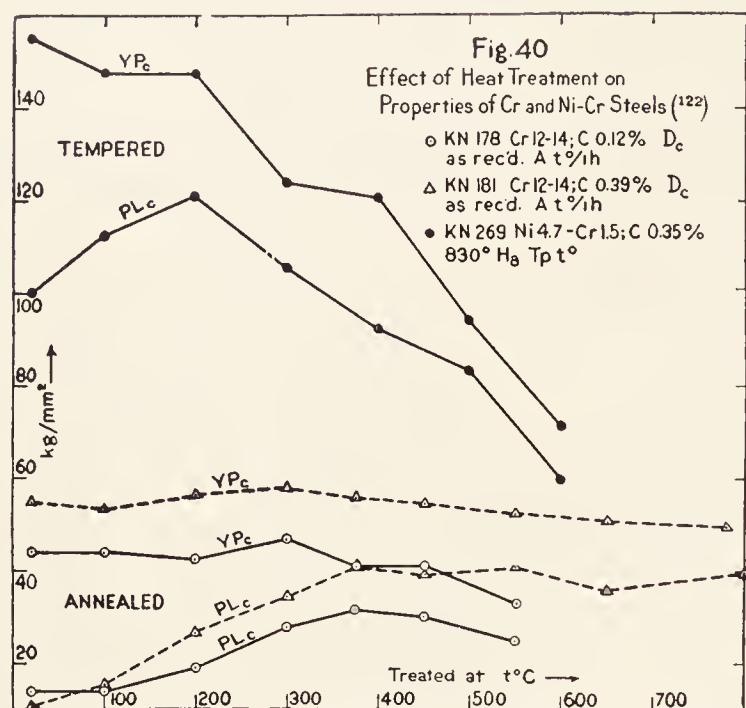




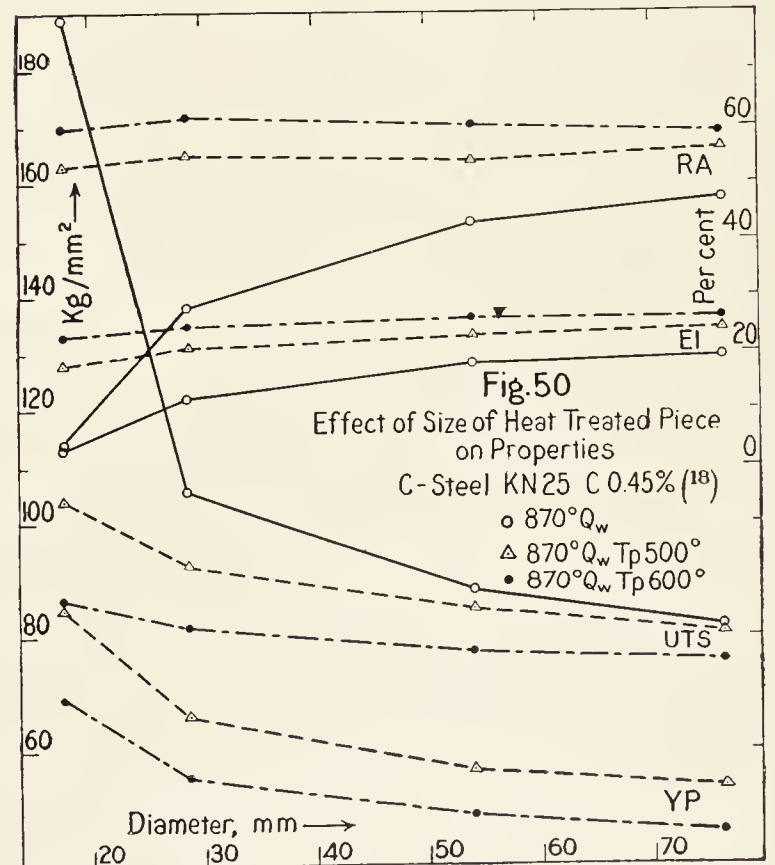
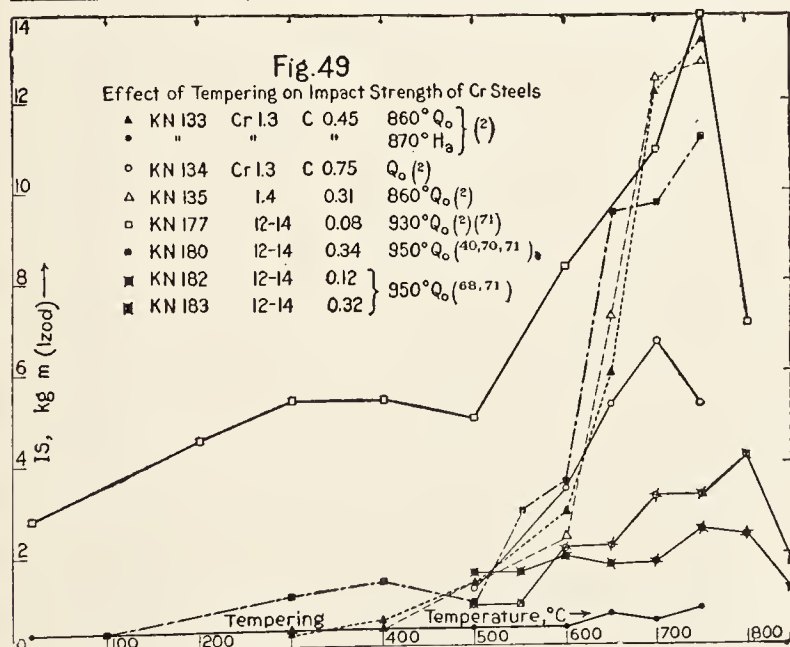
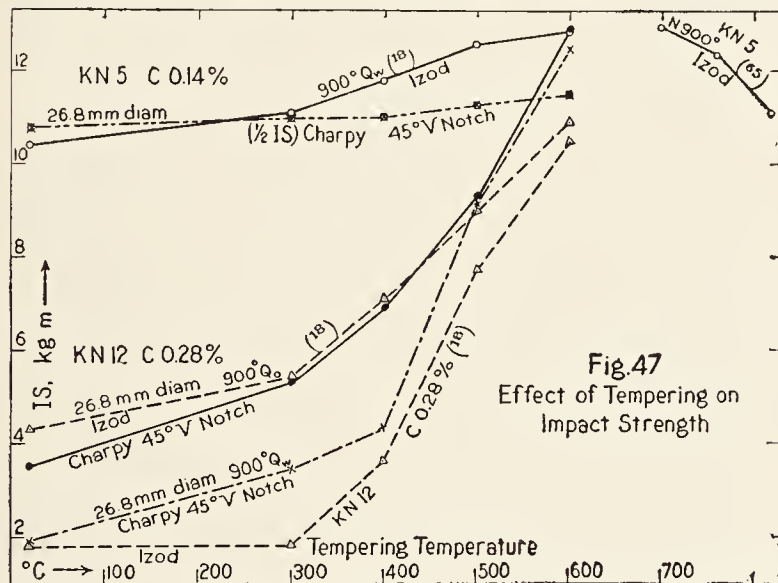
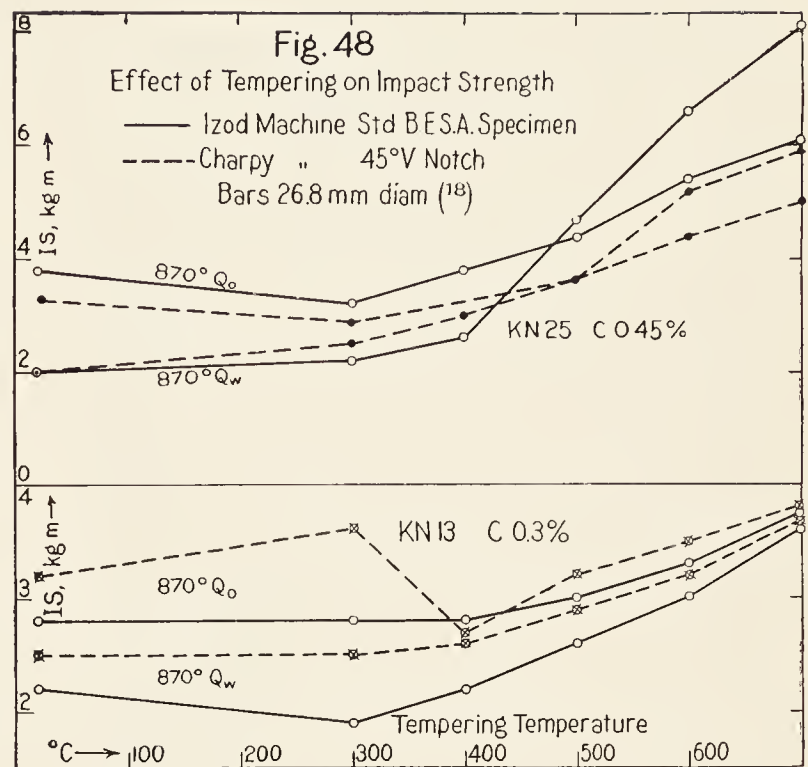
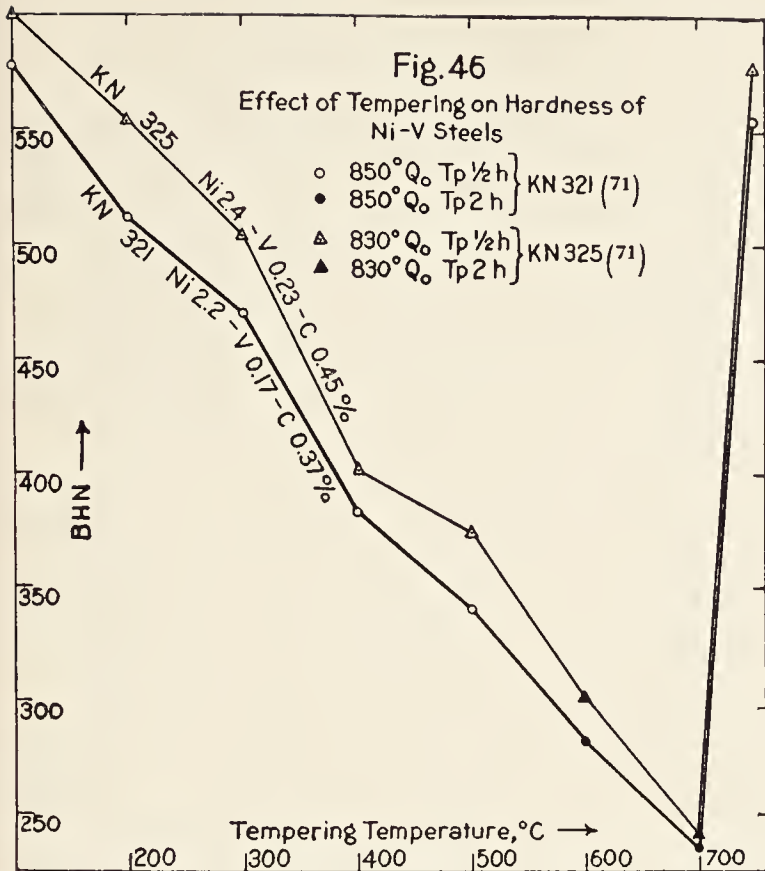












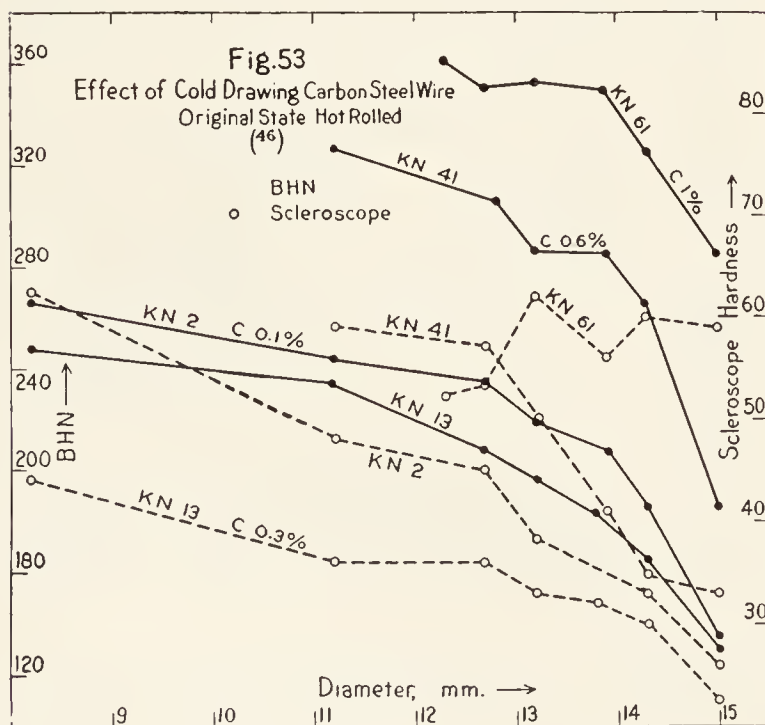
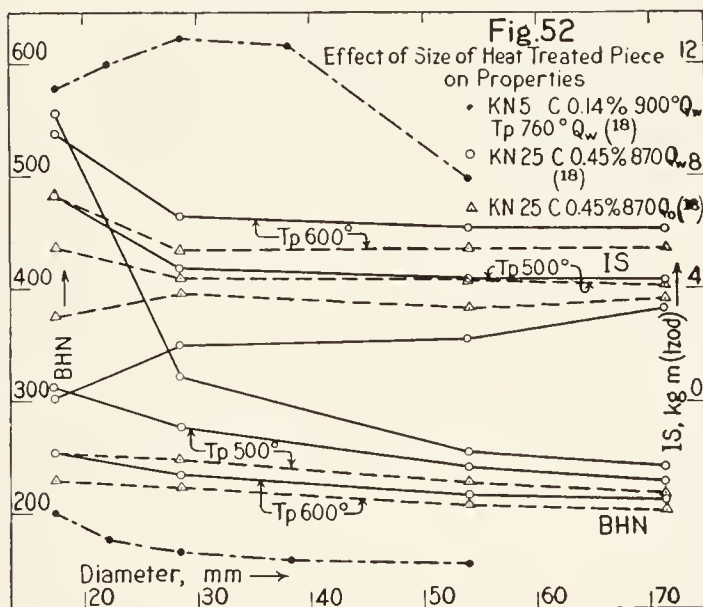
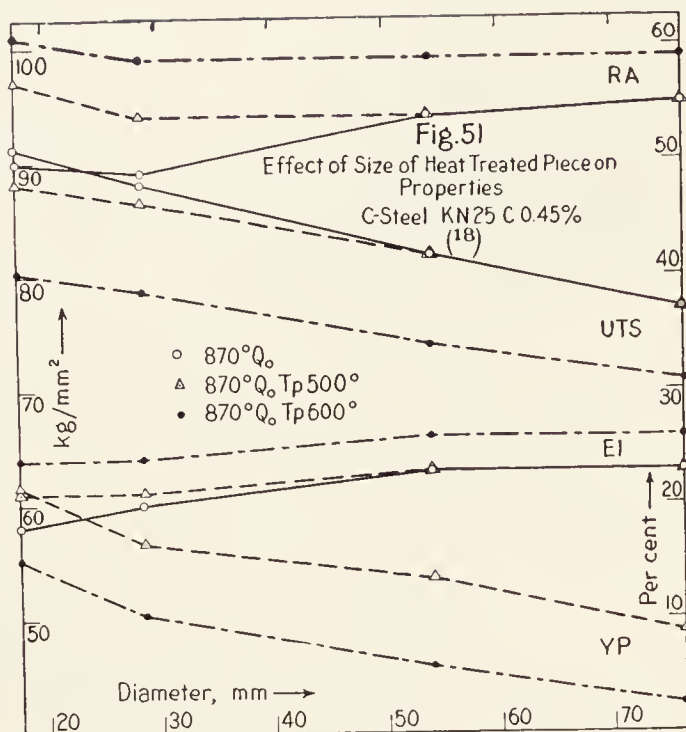


TABLE 4, PART I.—CR STEELS (TENSILE, HARDNESS AND IMPACT TESTS)

For compression tests *v.* Fig. 40Subscript <sub>o</sub> indicates rate of cooling through critical range

Key No.	Treatment*	BHN	UTS	YP	El <sub>a</sub>	RA	IS†	Lit.
120	931° C <sub>a</sub> 0.7 <sub>o</sub> /m ...		52.1	28.6	31	47	IS <sub>x</sub> †	(108)
	I { 700°/60 C <sub>a</sub> § ...	143	58.2	36.3	35	68	15.9	
	600°/60 C <sub>a</sub> § ...	161	64.6	47.6	31	64	13.2	
	II { 735°/140 C <sub>a</sub> § ...	139	54.6	38.5	37	68	15.0	
	550°/20 Q <sub>w</sub> ...	184	67.8	50.3	28	57	7.5	
	1070° C <sub>a</sub> 4 <sub>o</sub> /m ...	123	51.7	31.8	34	51	5.5	
121	A 790° ...	212	74.5	36.5	18.5	20.5		(111)
	790° Q <sub>w</sub> ...	627	127.5					
	790° Q <sub>o</sub> ...	418	141.6	86.2	3.5	6		
	375° ...	387	137.7	93.5	3.5			
	Same, 460° ...	430	138.4	97.7	2.5			
	560° ...	375	125.4	77.9	4			
	650° ...	321	112.1	67.1	11	13.3		
122	931° C <sub>a</sub> 0.7 <sub>o</sub> /m ...		56.0	33.4	31	47		(108)
	I { 700°/60 C <sub>a</sub> § ...	165	63.0	42.4	35	68	12.3	
	600°/60 C <sub>a</sub> § ...	178	67.1	45.3	31	64	10.3	
	II { 735°/140 C <sub>a</sub> § ...	152	59.0	41.8	37	68	12.5	
	550°/20 Q <sub>w</sub> ...	194	69.4	49.8	28	57	7.7	
	1070° C <sub>a</sub> 4 <sub>o</sub> /m ...	133	54.5	32.7	34	51	4.25	
123	A 800°/1.5 d C <sub>f</sub> 3 d		68.0	32.2	24.5	40.5		(9)
124	C <sub>a</sub> ...		109.1		PL = 79.1	16.5		(119)
125	C <sub>a</sub> ...		35.4		PL = 22.5	75		(119)
126	931° C <sub>a</sub> 0.7 <sub>o</sub> /m ...		53.6	33.9	33	53.5		(51, 79, 108)
	I { 700°/60 C <sub>a</sub> § ...	167	60.8	45.0	32	70	19.0	
	600°/60 C <sub>a</sub> § ...	180	65.8	49.0	27	65	16.2	
	II { 735°/140 C <sub>a</sub> § ...	157	58.3	40.7	34	69	20.0	
	550°/20 Q <sub>w</sub> ...	214	72.5	52.5	25	58	7.5	
	1070° C <sub>a</sub> 4 <sub>o</sub> /m ...	126	52.7	31.0	34	53.5	6.25	
	1000° Q <sub>o</sub> Tp { Q <sub>w</sub> ...	198	66.6	43.0	28	67	6.35	28.3
	650°/120 C <sub>b</sub> ...	192	63.9	41.7	28	67	5.5	34.6
	900° Q <sub>o</sub> { 60 C <sub>a</sub> ...	193	66.8	45.2	27	69	7.35	34.6
	120 Q <sub>w</sub> ...	194	64.1	42.3	30	70	7.35	31.5
	120 C <sub>b</sub> ...	192	63.5	42.3	30	70	6.8	34.6
	900° { 600° ...	199	67.7	45.2	27	65	5.5	36.2
	Q <sub>o</sub> { 550° ...	215	71.6	50.2	24	59	4.7	42.5
	500° C <sub>a</sub> {	216	71.8	49.4	23	59	3.9	44.1
	820° { 650° ...	185	63.6	41.4	31	70	6.65	36.2
	Q <sub>o</sub> { 600° ...	193					5.7	
	550° C <sub>a</sub> {	210	66.8	42.0	28	65	4.3	37.8
	500°		70.6	46.4	25	62		39.4
127	A 850°/60 C <sub>f</sub> ...	210		ScH = 32				(87)
	850° { 500° ...	350		ScH = 54				
	Q <sub>o</sub> Tp { 275° ...	515		ScH = 70			IS <sub>x</sub> †	
128	931° C <sub>a</sub> 0.7 <sub>o</sub> /m or VI ...	125	54.4	28.0	32	47	6.5	(87, 108)
	I { 700°/60 C <sub>a</sub> § ...	167	63.6	48.8	31	69	16.4	
	600°/60 C <sub>a</sub> § ...	196	70.5	55.3	27	66	13.1	
	III§ or V§ ...	161	61.7	47.8	33	70	18.0	
	IV§ or V <sub>a</sub> § ...	209	74.9	57.9	26	63	13.6	
	R (v. Figs. 34 and 45) ...	174	67.6	40.7	24.5	54.5		23
	RW 815° C <sub>a</sub> ...	162	64.9	39.2	28	59.5		23
	RW 815° C <sub>f</sub> ...	146	57.1	32.7	26	50		22
130	A 800°/1.5 d C <sub>f</sub> 3 d		68.2	29.6	22.5	39		(9)
131	C <sub>a</sub> ...		132		PL = 132	7.5		(119)
132	C <sub>a</sub> ...		56.5		PL = 43	58		(119)
133-135	<i>v.</i> Figs. 35, 36 and 49							
136	931° C <sub>a</sub> 0.7 <sub>o</sub> /m or VI ...	124	54.4	28.0	32	47	5.5	(51, 79, 108)
	I { 700° ...	189	63.6	48.8	31	69	18.0	
	600° C <sub>a</sub> {	211	70.5	55.8	27	66	12.9	
	III or V§ ...	163	61.7	47.9	33	70	18.5	
	IV or V <sub>a</sub> § ...	240	74.9	57.9	26	63	12.2	



TABLE 4, PART I.—CR STEELS (TENSILE, HARDNESS AND IMPACT TESTS).—(Continued)

For compression tests *v.* Fig. 40

Key No.	Treatment*	BHN	UTS	YP	El <sub>a</sub>	RA	IS <sub>†</sub>	Lit.
136	900°/30 C <sub>a</sub> .....	183					IS <sub>u</sub>	PL
	1000°/Q <sub>o</sub> Tp { Q <sub>w</sub>	210	71.3	53.8	25	64	8.2	37.8
	650°/120 C <sub>s</sub>	207	69.9	52.4	25	64	5.7	45.7
	650°/60 C <sub>a</sub>	225	73.5	56.4	25	69	9.3	50.4
	650°/120 Q <sub>w</sub>	205	69.9	52.7	26	69	9.1	40.9
	650°/120 C <sub>s</sub>	200	67.7	51.5	25	69	8.6	45.7
	600°/120 C <sub>a</sub>	229	78.7	60.5	23	65	7.6	52.0
	550°/120 C <sub>a</sub>	257	84.2	68.1	21	58	5.0	58.3
	500°/360 C <sub>a</sub>	255	84.3	67.7	20	57	3.5	59.8
	820° { 650°	198	67.2	49.4	26	70	9.3	44.1
	Q <sub>o</sub> { 600°	223	73.8	57.0	23	64	7.5	48.8
	Tp { 550° C <sub>a</sub>	244	81.4	64.3	21	61	4.4	56.7
137	As received.....	150						(105, 107)
	950° C <sub>a</sub> .....	150	52.6	33.0				
	A 950° 35 h C <sub>f</sub> ...	115	52.0	25.2				
	850° { 400°	375	107.9	105.4				
	Q <sub>w</sub> { 550° C <sub>a</sub>	305	91.4	86.6				
	Tp { 700°	195	64.9	50.4				
138	As received.....	179						(11, 105, 107, 108)
	As received, { 805°	205	73.8		26.5			
	A { 850°	195	71.1	39.4	26.5			
	960°	146	54.8	28.3	23.5		IS <sub>x†</sub>	
	931° C <sub>s</sub> 0.7c°/m or VI§.....	139	57.3	23.0	28	51	4.5	
	I { 700°	200	73.8	60.1	27	69	15.0	
	600°	248	88.1	76.6	22	62	12.0	
	III§ or V§.....	170	65.5	53.5	31	72	17.5	
	IV§ or V <sub>a</sub> §.....	253	88.7	78.7	19	57	11.0	
	950° C <sub>a</sub> .....	187	71.8	44.1	26	62.5		
	A 950°/35 h C <sub>f</sub> ...	116	47.8	22.7	37	70.5		
	850° { 400°	418	157.4	144.8	9.5	37		
	Q <sub>w</sub> { 550° C <sub>a</sub>	347	125.4	119.4	15	52		
	Tp { 700°	241	86.3	74.0	22.5	67		
139	As received.....	196						(105, 107)
	900° C <sub>a</sub> .....	242	96.1	66.1	20	55.5		
	A 950°/35 h C <sub>f</sub> ...	149	59.3	20.2	28	55.5		
	800° { 400°	454	176.6	164.2	9	30		
	Q <sub>w</sub> { 550° C <sub>a</sub>	382	141.1	133.9	13	42.5		
	Tp { 700°		98.3	89.8	21	61.5		
140	As received.....	290						(105, 107)
	900° C <sub>a</sub> .....	298	107.0	88.2	16	40		
	A 950°/35 h C <sub>f</sub> ...	226	78.5	50.5	21.5	62		
	800° { 550°	415	151.8	148.0	10	32.5		
	Q <sub>w</sub> { 700° C <sub>a</sub>	265	98.4	89.4	21	56		
141	As received.....	319						(11, 105, 107, 108, 119)
	900° C <sub>a</sub> .....	262	112.0	81.8	10	18		
	As received, { 805°	205	73.0	39.4	23			
	A { 850°	200	70.3	42.0	31			
	960°	270	96.0	55.0	9			
	960° Q <sub>o</sub> Tp { 600°		135.0		6			
	650°	477						
	A 950°/35 h C <sub>f</sub> ...	205	63.2	29.6	32	63.5		
	800° { 550°	402	150.6	145.6	8.5	28		
	Q <sub>w</sub> { 700° C <sub>a</sub>		99.3	90.5	20	52		
142	FA   .....		77	33-56	18.5-20.5			(35)
	FA ⊥.....		63	30-53	13-21			
143	931° C <sub>s</sub> 0.7c°/m or VI§.....	162	67.0	29.8			4.0	
	I { 700°	212	75.8	65.0			12.0	
	600°	270	100.2	85.5			9.2	
	III§ or V.....	172	66.1	56.0			16.5	
	IV§ or V <sub>a</sub> .....	300	96.4	85.0			7.5	
							IS <sub>u</sub>	PL
145	1000° Q <sub>o</sub> Tp { Q <sub>w</sub>	253	84.7	69.4	25	67	8.15	48.8
	650°/120 C <sub>s</sub>	244	80.7	65.5	25	68	3.7	53.6

TABLE 4, PART I.—CR STEELS (TENSILE, HARDNESS AND IMPACT TESTS).—(Continued)

For compression tests *v.* Fig. 40

Key No.	Treatment*	BHN	UTS	YP	El <sub>a</sub>	RA	IS <sub>u</sub>	PL
145	900° { 690°/120 C <sub>a</sub>	209	71.1	58.1	27	70	10.4	47.2
	Q <sub>o</sub> { 650°/60	255	85.2	70.1	23	69	8.7	53.6
	650°/120 Q <sub>w</sub>	246	80.8	63.8	25	70	9.0	39.4
	Tp { 650°/120 C <sub>s</sub> ..	236	77.9	61.2	25	70	4.55	48.8
	900° { 600°/120 C <sub>a</sub>	296	97.6	81.7	20	61	3.3	64.5
	Q <sub>o</sub> { 550°/120	342	116.0	102.0	16	56	1.8	77.2
	Tp { 500°/360	391	130.7	119.3	14	47	0.7	93.0
	820° { 650°	225	77.3	63.3	25	65	12.7	52.0
	Q <sub>o</sub> { 600°	281	95.6	84.4	20	60	3.9	61.5
	550°	325	110.3	100.2	18	59		77.2
	Tp { 700°.....		78.1	64.7	25	68	13.6	
	750°.....		69.3	59.0	29	71	15.4	
							IS <sub>x†</sub>	Lit.
	931° C <sub>s</sub> 0.7c°/m or VI§.....	162	67.3	29.2	24	45	4.5	(2, 51, 79, 108)
	I { 700° or V§.....	173	71.5	63.5	27	67	15.5	
	600° or V <sub>a</sub> §.....	287	101.2	80.9	18	57	8.1	
	I <sub>a</sub> { 700°	182	66.0	53.4	29	69	17.8	
	600°	252	81.5	68.9	19	58	5.9	
147	As received, { 850°	137	50.6	23.6	35			(11, 108)
	A { 960°	163	61.1	29.9	26			
	960° Q <sub>o</sub> Tp							
	610°/60.....		88.6		19			
	931° C <sub>s</sub> 0.7c°/m...		55.2	26.1	32	67		
	I { 700°		65.9	53.5	29	72		
	600°		87.1	79.4	19	61.5		
	I <sub>a</sub> { 700°	191	65.4	51.4	28	72	17.4	
	600°	254	83.9	70.5	22	65	8.9	
	II 780°/120 C <sub>s</sub> §...	163	59.0	52.0	35	73.5	22.0	
	1070° C <sub>s</sub> 4c°/m...	142	46.7	28.5	36	67	6.5	
148	931° C <sub>s</sub> 0.7c°/m or VI§	166	57.8	27.6	31	67	4.5	(108)
	I { 700°		70.7	57.8	26	66		
	600°		95.1	87.9	18	56		
	I <sub>a</sub> { 700°	186	70.3	56.5	26	66	16.2	
	600°	261	93.5	78.3	20	56	5.7	
	III§ or V.....	176	68.1	58.0	30	68	15.0	
	IV§ or V <sub>a</sub> .....	281	94.8	85.0	18	55	8.1	
149	As received, { 805°	192	78	37	25			(11)
	A { 850°	225	80	37.8	22			
	960°	228	84	42	15			
	960° Q <sub>o</sub> Tp 650°..		120		10			
	960° Q <sub>o</sub> 500°/60 C, Tp <sub>2</sub> 650°.....	311						
150	C <sub>a</sub> .....		60.3	PL = 56.5	62			(119)
151	C <sub>a</sub> .....		133.3	PL = 84.4	7.5	IS <sub>u</sub>		(119)
152	850° Q <sub>o</sub> Tp 700°..		70.3	51.3	15	57	9.25	(2)
153	931° C <sub>s</sub> 0.7c°/m or VI	165	54.8	24.6	36	73	5.1	(108)
	I { 700°		71.7	58.0	28	65	IS <sub>x†</sub>	
	600°		93.9	83.6	18	56		
	I <sub>a</sub> { 700°	190	71.8	55.9	25	66	14.0	
	600°	270	88.1	76.7	20	57	5.9	
	III <sub>a</sub> § or V.....	180	68.6	50.4	31	68.5	15.1	
	IV§ or V <sub>a</sub> .....	278	100.8	89.4	18	55	7.1	
154	A.....		59.4	25.4	31.5	64		(9)
155	As received, { 805°	210	74.4	41.0	26			(11)
	A { 850°	202	68.5	37.8	30.5			
	960°	228	82.9	41.0	19			
	960° Q <sub>o</sub> Tp 650°/60		119.2		12.5			
	960° Q <sub>o</sub> 500°/60 C Tp <sub>2</sub> 650°							
156	931° C <sub>s</sub> 0.7c°/m...		52.8	21.3	34	67		(108)
	I { 700°		65.7	55.2	29	72		
	600°		87.1	79.2	21	63		
	I <sub>a</sub> { 700°	187	66.4	54.2	28	71	18.7	
	600°	248	88.1	77.1	22	63	8.1	

TABLE 4, PART I.—CR STEELS (TENSILE, HARDNESS AND IMPACT TESTS).—(Continued)

For compression tests *v.* Fig. 40

Key No.	Treatment*	BHN	UTS	YP	El <sub>a</sub>	RA	IS <sub>x</sub> †	Lit.
156	II { 780° 120 740° C <sub>s</sub> § 550°/120 Q <sub>w</sub> ...	154 173 344	56.6 60.1 129.4	45.2 45.2 105.5	36 30 15	74.5 73 46	23.5 19.2 5.1	
	1070° C <sub>s</sub> 4c°/m...	135	53.6	25.2	34	63	1.5	
157	931° C <sub>s</sub> 0.7c°/m or VI <sub>a</sub> §	192	59.7	31.1	32	69	3.5	(108)
	I { 700° 600° 60 700° C <sub>a</sub> § 600°	205 263	76.6 96.5 77.3 90.7	61.1 87.9 59.4 72.7	26 18 25 19	60.5 52 61.5 53.5	8.9 5.1	
	III § or V.....	203	74.3	53.6	29	63	10.2	
	IV § or V <sub>a</sub> .....	287	101.8	91.9	18	50	5.05	
158	931° C <sub>s</sub> 0.7c°/m...		51.7	23.4	36	70		(108)
	I { 700° 600° 60 C <sub>a</sub> §		65.1 83.8	52.8 74.8	29 20	72 64		
	I <sub>a</sub> { 700° 60 600° C <sub>a</sub> §	187 240	66.9 84.7	54.4 76.0	28 21	72 66	18.7 10.3	
	II { 780° 120 740° C <sub>s</sub> § 550°/20 Q <sub>w</sub> ...	158 166 348	58.0 59.0 130.0	42.6 45.5 94.0	34 30 14	73 72 46	20.7 21.1 5.05	
	1070° C <sub>s</sub> 4c°/m...	136	52.7	24.2	34	65	1.7	
159	850° Q <sub>o</sub> Tp { 500° 600° 700°		144.7 92.1 76.6	130.0 77.3 55.5	10 18 23	30.5 50 60.5	IS <sub>u</sub> 2.1 10.4	(2, 11)
	As received, { 805° A { 850° 960°	200 160 170	69.1 57.6 63.3	59.8 25.2 33.0	25 34 25			
	960° Q <sub>o</sub> Tp 650°..		95.0		17			
	960° Q <sub>o</sub> 500°/60, Tp <sub>2</sub> 650°.....	286						
160	820° Q <sub>o</sub> Tp 650°..		103.3	93.7	15.5	54.5		(1)
	Same, { 700° tested at { 900°		26.8 11.0					
161	As received, A { 805° 850° 960°	223 210 202	78.2 74.3 70.0	42.5 37.8 37.8	32.5 26.5 26.5			(1, 11)
	820° Q <sub>o</sub> Tp 650°..		122.4	114.2	11.5	28.5		
	Same, { 700° tested at { 900°		29.0 11.80					
	960° Q <sub>o</sub> Tp 650°..	350						
162	C <sub>a</sub> .....		124.3	PL = 60		17.6		(119)
163	C <sub>a</sub> .....		150.6	PL = 100		7.5		(119)
164	As received, A { 805° 850° 960°	175 174 177	64.3 62.1 69.0	56.7 33.0 31.5	30 32 23.5			(11)
	960° Q <sub>o</sub> 500°/60 Tp <sub>2</sub> 650°.....	255						
165	As received, A { 805° 850° 960°	223 207 196	83.1 73.8 68.3	53.5 37.8 37.8	18 23.5 25			(11)
166	C <sub>a</sub> .....		143.0	PL = 130.0		4.5		(119)
167	C <sub>a</sub> .....		94.1?	PL = 79		0	IS <sub>u</sub>	(119)
168	875° Q <sub>o</sub> Tp { 500° 600° 700°		149.0 89.3 72.4	132.8 73.1 52.7	9 18 22	25 50 57	4.0 11.4	(2)
171	C <sub>a</sub> .....		139.3	PL = 102		0		(119)
172	A.....		58.5	26.0	29	56.5		(9)
173	As received, { 805° A { 850° 960°	185 190 200	54.8 52.4 50.9	33.0 25.1 28.4	34.4 32.0 28.9			(11)
174	As received, { 805° A { 850° 960°	153 143 140	65.0 67.2 67.1	28.3 31.5 37.8	31 27 26			(11)

TABLE 4, PART I.—CR STEELS (TENSILE, HARDNESS AND IMPACT TESTS).—(Continued)

For compression tests *v.* Fig. 40

Key No.	Treatment*	BHN	UTS	YP	El <sub>a</sub>	RA	IS <sub>x</sub> †	Lit.
175	900° H <sub>a</sub> Tp 700°..		67.7	50.4	21	48	6.8¶	(1)
176	900° H <sub>a</sub> Tp { 650° 700° 750°		93.5 83.6 78.7	72.4 70.3 57.7	19 21 24	41 56 47	1.65 2.8 3.2	(2)
177	A 1000°..... A <sub>c</sub> { 950°..... 850°..... 1000° Q <sub>o</sub> 750°/6 h C <sub>f</sub> .....	143 143 143 165	48.8	26.8	40	74.5	8.85 13.85	(40, 71)
	<i>v.</i> Figs. 9, 37, and 49							
178	<i>v.</i> Fig. 25							
179	950° Q <sub>o</sub> { 650° Q <sub>w</sub> Tp { 250° Q <sub>w</sub>	217** 444††	77.2 168.0	62.7†† 149.5	22 7	55 59.5	6.65 1.1	(65, 71)
180	<i>v.</i> Figs. 37, 45, 49							
181	As received, D <sub>c</sub> ... A { 805°..... 850°..... 960°.....	185 190 192	80.1 69.2 66.8 68.6	61.4§§ 34.6 33.0 31.5	21 33 30 23	50		(2, 11, 122)
	<i>v. also</i> Figs. 10 and 25							
182	<i>v.</i> Figs. 11, 38, 45, 49							
183	975° Q <sub>o</sub> Tp 700°..	255	88.1	70.3¶¶	21.5	53.0	2.8	(68)
	<i>v. also</i> Figs. 11, 38, 45, 49							
184	900° H <sub>r</sub> Tp 700°.. Same, tested at { 700° 800° 900° 1000°		91.6 20.8 12.4 11.8 6.0	64.3	15.5	30.5	1.0 2.5 3.5 5.0 6.1	(1)
186	A.....		69.2	32.8	20	36	IS <sub>u</sub>	(9)
187	875° Q <sub>o</sub> Tp { 500° 600° 700° 750°		132.9 92.8 71.0 74.5	106.2 69.6 45.7 49.9	4 13.5 20 23	5 37.5 40.5 50	5.1 9.7 8.0	(2)
188	A.....		89.5	76.7	16	26.5		(9)
190	A.....		77.3	54.8	12.0	21.5		(9)
191	As cast..... R or F.....		28-63 56-91	21-56 46-78	2-0 26-8	3-0 50-10		(36)

\* Italicized numerical values are for the alternative treatments (as indicated by footnote§).

† For meaning of subscripts *v.* p. 396.

‡ Tested on the Guillery machine.

§ Meanings of treatments denoted by Roman numerals are: I = 950°/30 C<sub>a</sub> 860°/30 Q<sub>o</sub> Tp; I<sub>a</sub> = 950°/30 C<sub>a</sub> 870°/30 C<sub>a</sub> Tp; II = 1065°/30 C<sub>a</sub> 850°/60 Q<sub>o</sub> Tp; III = 950°/60 C<sub>a</sub>, 825°/30 Q<sub>o</sub> 735°/255 C<sub>a</sub> 630°/120 C<sub>a</sub>; III<sub>a</sub> = 915°/60 C<sub>a</sub> 820°/30 Q<sub>o</sub> 750°/255 C<sub>a</sub>, 620°/140 C<sub>a</sub>; IV = 950°/60 C<sub>a</sub> 825°/30 Q<sub>c</sub> 625°/30 C<sub>a</sub>; V = 1000°/20 C<sub>a</sub>, 830°/30 Q<sub>o</sub> 745°/60 C<sub>a</sub>; V<sub>a</sub> = 1000°/20 C<sub>a</sub> 830°/30 Q<sub>o</sub> 600°/20 Q<sub>w</sub>; VI = 1020° C<sub>s</sub> 2c°/m; VI<sub>a</sub> = 1070° C<sub>s</sub> 4c°/m.

¶ ScH = 41.

¶¶ Charpy machine, type of specimen not stated.

\*\* ScH = 35.

†† PL = 47.2.

‡‡ ScH = 64.

§§ PL = 14.2 on 2 in., 11.0 on 8 in., EL = 11.0 on 8 in.

¶¶ PL = 53.2.

||| 900° H<sub>o</sub> Tp 500°, IS<sub>u</sub> = 1.1.900° H<sub>o</sub> Tp 600°, IS<sub>u</sub> = 2.1.900° H<sub>o</sub> Tp 700°, IS<sub>u</sub> = 4.15.

TABLE 4, PART II.—SHEAR AND TORSION TESTS ON CR STEELS Tests on air cooled specimens on Fremont shear machine (119)

Key No.....	124	131	132	141	144	151	162	163	167	171
USS.....	49	57	19	56	36.5	56	40	51.5	39.5	67.5



TABLE 4, PART II.—SHEAR AND TORSION TESTS ON CR STEELS.—  
(Continued)

## Torsion tests

Key No.	Treatment	USSC*	TMR†	YPS	PLS	T <sub>w</sub> , °/cm	Lit.
127‡	A 850°/60 C <sub>f</sub> .... 850° Q <sub>o</sub> { 500°/60 Tp { 275°/60	48 70.5 103.5	65 94 138		29 72 90	33.8 17.7 4.7	(87)
128‡	A 850°/60 C <sub>f</sub> .... 850° { 515° Q <sub>w</sub> { 570° } 60 { Tp { 620°	44 61.5 59 56.5	58.5 82 79 75.5		25 63.5 57 54	50.4 26.4 28.7 39.4	(87)
179§	950° { 650° Q <sub>w</sub> Q <sub>o</sub> Tp { 250° Q <sub>w</sub>	52 90	69 120	41 79.5		107.5 15.3	(65)

\* Stress assumed uniform throughout cross-section.

† TMR = 1.333 USSC.

‡ Size of specimen unknown.

§ Specimen 1¾ in. × ⅝ in. diam.

TABLE 5.—CR-V STEELS  
See also Figs. 12, 26, 28, and 39

Key No.	Treatment	BHN	ScH	UTS	YP	El <sub>a</sub> *	RA	Lit.
192	As rolled.....			43.5	34.3	38	63	(126)
194	As rolled..... A 620°.....			56.7 56.1	37.0 35.9	28 30.5	45 55.5	(126)
195	As received..... 927° Q <sub>o</sub> 870° Q <sub>o</sub> Tp 650°.....	302 300	42 48	96.1 101.8	59.9 94.9	15.5 18	45.5 62	(53)
196	As rolled..... A 650°/30..... A 850°/30.....			76.5 79.1 61.1	57.0 60.2 44.1	24 23 26	56.5 56.4 65	(126)
198	A 800-900° ..... Q <sub>o</sub> Tp.....			114.2 126.5	71.7 84.9	9 12.5	44 46	(126)
199	S 1200°/12h { 750° C <sub>m</sub> W <sub>2</sub> { 950° 500° Q <sub>o</sub> Tp 350°.. 690° Q <sub>o</sub> Tp 350°.. 690° Q <sub>o</sub> Tp 600°.. 870° Q <sub>o</sub> Tp 350°.. 900° Q <sub>o</sub> Tp 600°.. 1000° Q <sub>o</sub> Tp 350°.			65.4 88.7 84.6 82.8 83.5 93.5 84.5 92.1	42.5 59.2 61.3 59.8 60.3 78.4 68.4 79.5	23 26 26 25 23 22 20	38 49.5 51 51 50 51 56.5 37.5	(126)
200	As rolled..... A 800°/30.....			104.2 83.6	66.9 61.9	16.5 23.5	40.5 52	(126)
201	850° Q <sub>o</sub> Tp 650°..			93.5	70.9	18	50	(71)
202	850° Q <sub>o</sub> Tp 420°..	444	63	169.0	140.9	8.5	24	(65)
203	850° Q <sub>o</sub> Tp 650° C <sub>a</sub>	255	41	89.0	76.5†	22	60.5	(65)

From torsion tests: No. 193 { (As received): USSC = 72.5, TMR = 97 } (16).  
(A): USSC = 51.5, TMR = 69No. 203, (850° Q<sub>o</sub> Tp 650° C<sub>a</sub>): USSC = 61.5, TMR = 82, YPS = 58, Total T<sub>w</sub> = 532° (65).Impact strength: No. 202, IS(Izod) = 1.9, IS<sub>w</sub> = 0.8 } (65).  
No. 203, IS(Izod) = 4.8\* For key Nos. 192, 194, 196, 199, 200 specimens are 2 in. × 0.75 in. diam.  
and for key No. 198 specimens are 2 in. × 0.375 in. diam.

† PL = 60.8.

TABLE 6.—COPPER STEELS  
Cold drawn copper steels (133, 134, 143)

Key No.	Treatment	Diam. mm	UTS	El
204	D <sub>o</sub> ..... D <sub>o</sub> ..... D <sub>o</sub> .....	4.37 3.23 2.34	129.1 158.0 194.5	5 <sub>k</sub> 5.5 <sub>k</sub> 5 <sub>k</sub>
207	A..... D <sub>o</sub> ..... D <sub>o</sub> .....	(5 SWG) 3.25 1.93	83.8 69.5 93.5	18 <sub>k</sub>
210	D <sub>o</sub> ..... D <sub>o</sub> ..... D <sub>o</sub> .....	5.59 2.95 1.83	128.0 165.4 207.6	5 <sub>k</sub> 4.5 3.5

TABLE 6.—COPPER STEELS.—(Continued)

Key No.	Treatment	Diam. mm	UTS	El
212	A..... D <sub>o</sub> ..... D <sub>o</sub> .....	(5 SWG) 3.25 1.85	74.8 66.6 112.2	15 <sub>k</sub>
213	D <sub>o</sub> 4 SWG..... D <sub>o</sub> ..... D <sub>o</sub> .....	5.21 2.92 1.30	93.7 141.9 205.4	3.5 <sub>k</sub> 3 2
216	AC > 24 h..... D <sub>o</sub> ..... D <sub>o</sub> ..... D <sub>o</sub> ..... A <sub>2</sub> D <sub>o</sub> ..... D <sub>o</sub> ..... D <sub>o</sub> ..... A <sub>2</sub> D <sub>o</sub> ..... D <sub>o</sub> .....	(5 SWG) 4.70 3.81 3.07 2.77 2.13 1.83 1.65 1.02	64.9 86.4 99.2 113.5 75.9 91.4 103.9 67.8 98.4	11 2 3 2.5 3 2 3.5 2 1.5
218	AC > 24 h..... D <sub>o</sub> ..... D <sub>o</sub> ..... D <sub>o</sub> ..... A <sub>2</sub> D <sub>o</sub> ..... D <sub>o</sub> ..... A <sub>2</sub> D <sub>o</sub> ..... A <sub>2</sub> D <sub>o</sub> ..... A <sub>2</sub> D <sub>o</sub> .....	(5 SWG) 4.70 3.81 3.07 2.77 2.13 1.83 1.42 0.99	89.9 114.2 128.2 151.3 91.4 111.5 125.2 146.8 154.4	8 3 3 4 3.5 2.5 3 3 2
221	A..... D <sub>o</sub> ..... D <sub>o</sub> .....	5.44 3.25 1.85	86.1 71.7 105.5	15 <sub>k</sub>
224	AC > 24 h..... D <sub>o</sub> ..... D <sub>o</sub> ..... D <sub>o</sub> ..... A <sub>2</sub> D <sub>o</sub> ..... D <sub>o</sub> ..... D <sub>o</sub> ..... A <sub>2</sub> D <sub>o</sub> .....	(5 SWG) 4.70 3.81 3.07 2.77 2.13 1.83 1.65	64.5 86.0 100.0 107.3 81.3 101.7 104.7 72.7	14 3 3 4 3 2 3 2
227	A..... D <sub>o</sub> ..... D <sub>o</sub> .....	5.49 3.25 1.88	92.1 66.7 100.8	12.5 <sub>k</sub>
233	AC > 24 h..... D <sub>o</sub> ..... D <sub>o</sub> ..... D <sub>o</sub> ..... A <sub>2</sub> D <sub>o</sub> ..... D <sub>o</sub> ..... D <sub>o</sub> ..... A <sub>2</sub> D <sub>o</sub> ..... A <sub>2</sub> D <sub>o</sub> .....	(5 SWG) 4.70 3.81 3.07 2.77 2.13 1.83 1.65 1.02	65.5 82.4 94.5 103.1 88.2 105.8 107.3 76.0 106.6	12 2 3 3.5 2.5 2.5 2.5 2 1.5

## Cast, rolled and forged copper steels

Key No.	Treatment	Diam.*	BHN†	UTS	YP	El‡	RA	Torsion data§	Lit.
205	As cast..... A 800°..... A 1000°..... A 1200°.....	A A A A		36.8 37.4 39.0 38.1	18.3 17.9 24.7 20.2	24 <sub>d</sub> 22 <sub>d</sub> 28 <sub>d</sub> 28.5 <sub>d</sub>	53 59.5 67 64	Specimens 100 mm × 18 mm diam. (as rolled)	(82)
206	F..... CR Q <sub>w</sub> Tp DR..... CR Q <sub>o</sub> Tp DR.....	B B B		60.0 103.0 82.5		13 <sub>d</sub> 16 <sub>d</sub> 23 <sub>d</sub>	48.5 45 48.5		(17)
208	R.....	D	120	39.2	28.4	25 <sub>f</sub>	42		(83)
209	G.....	A	170	61.2	31.5	17 <sub>d</sub>	20		(82)

TABLE 6.—COPPER STEELS.—(Continued)  
Cast, rolled and forged copper steels

Key No.	Treatment	Diam.*	BHN†	UTS	YP	EL‡	RA	Torsion data§	Lit.
211	F.....	B		62.0		23d	48.5		(17)
	Q <sub>w</sub> Tp.....	B		97.9		10.5d	58		
	Q <sub>o</sub> Tp.....	B		75.7		15d	56		
214	R.....	B	146	47.1	38.7	25.5d	66	USSC = 39.5	(17)
	A 900°.....	B	143	41.5	26.9	28d	60	TMR = 52.5	
	870° Q.....	B	311	67.0	49.7	16d	53	YPS = 31	
	Same, Tp 300–350°.....	B	311	72.2	51.2	8.5d	60	Tw = 77	
215	R.....	B	202	65.5	48.6	20d	48.5	USSC = 43	(17)
	A 900°.....	B	166	54.7	33.4	23.5d	43	TMR = 57.5	
	870° Q.....	B	627	76.5	76.5	1.5d		YPS = 33	
	Same, Tp 300°.....	B	460	139.0	135.1	1.5d		Tw = 19.6	
216	R.....			73.3	39.4	19	20.5		(133)
217	R.....	B	255	83.5	62.1	12d	22.5	USSC = 68.5	(17)
	A 830°.....	B	228	72.3	41.1	16.5d	43	TMR = 91.5	
	830° Q <sub>w</sub> .....	B	817					YPS = 54.5	
	Same, T <sub>D</sub> 300–350°.....	B	555	153.0	158.0	0d	0	Tw = 27.2	
219	R  .....	B	286	102.8	71.7	5.5d	4	USSC = 76.5	(17)
	W <sub>2</sub> 825° C.....	B	235	79.4	48.0	16d	34	TMR = 102	
	825° Q <sub>h</sub> .....	B	332	103.0	76.0	8d	27	YPS = 51	
								Tw = 13	
220	F.....	B		66.3		20d	55		(17)
	CR Q <sub>w</sub> Tp DR.....	B		103.8		11d	57		
	CR Q <sub>o</sub> Tp DR.....	B		83.6		15d	55		
222	F.....	B		68.2		17.5d	61		(17)
	CR Q <sub>w</sub> Tp DR.....	B		112.2		9d	66		
	CR Q <sub>o</sub> Tp DR.....	B		81.5		13d	62		
223	As cast.....			28.8		10b			(12)
225	R.....	B	146	49.5	41.5	26.5d	60	USSC = 41.5	(17)
	A 900°.....	B	146	49.0	38.6	26d	57	TMR = 55	
	870° Q.....	B	311	92.8	83.3	5.5d	26	YP = 29	
	Same, Tp 300°.....	B	277	69.0	52.9	11.5d	66	Tw = 92.5	
226	R.....	B	207	64.5	45.2	20.5d	47	USSC = 48	(17)
	A 900°.....	B	196	60.6	40.9	20d	40	TMR = 64	
	870° Q.....	B	600	102.5	102.5	1.5d		YPS = 40.5	
	Same, Tp 300°.....	B	495	166.5	149.0	3.5d	7.5	Tw = 44.6	
227	R.....	B	418	96.0	55.3	12.5d	17	USSC = 71	(17)
	A 830°.....	B	223	75.5	42.4	8.5d	18	TMR = 94.5	
	830° Q.....		800					YPS = 59	
	Same, Tp 350°.....		600					Tw = 24.8	
228	R.....	B	364	110.0	69.3	6d	7	USSC = 69	(17)
	A 825°.....	B	277	80.0	56.5	16.5d	32	TMR = 92	
	825° Q <sub>h</sub> .....	B	311	92.5	70.0	8d	31	YPS = 54.5	
								Tw = 10.8	
229	R.....			66.4	44.1	23	35		(134)
231	1000° C <sub>a</sub> .....	C		34.8	30.8	30.5a	62		(6)
232	R.....	B	202	62.5	47.4	16d	58.5	USSC = 47	(17)
	A 900°.....	B	174	49.5	41.3	25d	58	TMR = 62.5	
	870° Q.....	B	311	112.0	106.0	5d	25.5	YPS = 44	
	Same, Tp 300°.....	B		111.0	102.4	6.5d	34	Tw = 70.2	
233	R.....			78.2	56.5	21.5	35		(134)
	A.....			74.3		20	36		
234	R.....	B	269	79.6	68.5	11d	31.5	USSC = 55.5	(17)
	A 900°.....	B	207	61.5	45.6	18d	40	TMR = 74	
	870° Q.....	B	800	75.0	75.0	1d		YPS = 49	
	Same, Tp 300°.....	B	495	167.0	155.0	2d	1.5	Tw = 29.6	
235	As cast.....			57.6		5b			(12)
238	R.....	B	375	117.0	97.5	1.5d	1.0	USSC = 74	(17)
	W <sub>2</sub> 825° C.....	B	277	84.0	63.7	14d	43	TMR = 98.5	
	825° Q <sub>h</sub> .....	B	311	107.5	86.9	4d	17	YPS = 66.5	
								Tw = 16.2	
240	As cast.....			72.0		5b			(12)
241	R.....	B	255	77.1	69.5	13d	46.5	USSC = 58	(17)
	A 900°.....	B	183	50.3	46.0	22d	63	TMR = 77.5	
	870° Q.....	B	351	137.9	106.0	7d	29.5	YPS = 61.5	
	Same, Tp 300°.....	B	325	100.0	85.5	11d	52	Tw = 18.3	
242	R.....	B	302	97.1	81.8	11d	23.5	USSC = 68.5	(17)
	A 900°.....	B	212	68.5	56.5	16d	42	TMR = 91.5	
	870° Q.....	B	782	100.2	100.2	1d		YPS = 65	
	Same, Tp 300°.....	B	782	173.0	157.9	1.5d	1.0	Tw = 18.3	

\* Diameters of tensile specimens: A = 10 mm, B = 13.8 mm, C = 14.33 mm, D = 20 mm.

† 10 mm ball, 3000 kg load.

‡ a = 2 in., d = 100 mm, f = 200 mm, k = 20 in., b = 1 in.

§ TMR = 1.333 USSC.

|| Broke near head.

COMPRESSION TEST ON CYLINDER 28.47 × 14.33 MM DIAM.  
(1000° C<sub>a</sub>)

Key No.	Compressive stress kg/mm <sup>2</sup>	31.5	63	94.5	126	157.5	Lit.
231	% compression.....	1.5	8	22	38.5	49.5	(6)

TABLE 7, PART I.—NICKEL CHROMIUM STEELS\* (TENSILE, HARDNESS AND IMPACT TESTS)

Key No.	Treatment	BHN	UTS	YP	EL	RA	IS <sub>a</sub> †	IS <sub>v</sub> ‡	Lit.
243	R <sub>h</sub> .....		46	26‡	37.5	61.5			(12a)
244	As received.....	255§	85.5	76.5	13	56			(71)
245	850° C <sub>a</sub> .....	174	63	45.5	33	65	10.3	11.6	(18)
	850° Q <sub>w</sub> Tp { 500° Q <sub>w</sub> 302 101 88 18 58 6.9 8.1 600° Q <sub>w</sub> 255 80 71 25 66 11.6 13.3 650° Q <sub>w</sub> 229 74 63 27 69 12.9 15.0								
	850° Q <sub>o</sub> { 300° 302 101 71 16 34 2.4 2.3 400° 302 97.5 69 16 47 3.2 3.0 500° 291 94.5 67 17 54 4.4 4.8 600° 262 85 69 21 62 9.7 10.0 650° 223 72.4 58 27 68 12.5 14.0 700° 212 69 55 29 70 12.9 15.5								
246	850° C <sub>a</sub>   .....	444	157	110	12	38	0.7	0.9	(18)
	850° Q <sub>w</sub> Tp   { 500° Q <sub>w</sub> 410 134 116.5 12 39 0.7 1.1 600° Q <sub>w</sub> 340 110 102.5 17 45 1.1 1.3 650° Q <sub>w</sub> 311 101 90 18 50 5.0 3.9								
	850° Q <sub>o</sub>    { 300° 477 181 128 11 36 0.4 .7 400° 444 162 135 11 36 .3 .6 500° 401 137 124.5 12 39 .4 .9 600° 321 112 101 17 47 1.0 1.6 650° 293 102 91 20 52 5.4 5.3								
	850° Q <sub>o</sub> .....	512	192	183	5	8	0.55		
	Same, Tp.. { 500° 364 129 115 13 40 0.4 650° Q <sub>w</sub> 255 89.5 72.5 23 59 5.65								
247	1000° Q <sub>o</sub> Tp { Q <sub>w</sub> ... 241 80.5 63 50.5 21 51 7.05 (80) 650°/120 C <sub>a</sub> ... 234 79.5 63 55 20 46 8.3								
	900° Q <sub>o</sub> Tp { 675°/120 C <sub>a</sub> 238 80 63.5 53.5 21 45 6.8 650°/120 Q <sub>w</sub> 245 82 67.5 53.5 19 46 6.8 650°/120 C <sub>a</sub> 242 81 65 58 19 46 1.0 650°/360 C <sub>a</sub> ** 227 76.5 60 52 21 45 7.2 600°/120 C <sub>a</sub> 270 91 77 63 18 39 4.85 550°/120 C <sub>a</sub> 300 99.5 86.5 69 14 39 1.95								
	820° Q <sub>o</sub> Tp { 650°/120 C <sub>a</sub> 244 81 65 58 21 47 6.8 600°/120 C <sub>a</sub> 270 90 75.5 63 18 41 4.7 550°/120 C <sub>a</sub> 301 100 86.5 71 15 37 1.95								
	FA, 850° Q <sub>o</sub> Tp 660° C <sub>a</sub> .....	224	75.5	56	49	20	51	4.3	
								IS <sub>w</sub> ††	
248	A 900°/90 C <sub>f</sub> .....	v. also	46	28		30.5	59	61.0	(89)
	Same, 870° Q <sub>o</sub> 760° /60 Q <sub>o</sub> 260°/60 C <sub>a</sub> .....	Fig. 21	57.3	35.5		21	67	95.0	
249	A 900°/90 C <sub>f</sub> .....	v. also	62.5	30		21	41	13.6	(89)
	Same, 825° Q <sub>o</sub> Tp 600°/60 C <sub>f</sub> .....	Fig. 22	86.2	71		20	58	34.2	
								IS <sub>u</sub>	
250	1000° Q <sub>o</sub> Tp { Q <sub>w</sub> ... 262 89 72.5 58 21 50 7.75 (80) 650°/120 C <sub>a</sub> ... 257 87.5 70.5 63 21 50 0.4								
	900° Q <sub>o</sub> Tp { 675°/120 C <sub>a</sub> 243 84 69 63 22 55 7.35 650°/120 Q <sub>w</sub> 258 87.5 72.5 58 20 50 7.9 650°/120 C <sub>a</sub> ** 252 84.5 70 66 20 50 0.55 650°/360 C <sub>a</sub> 236 80 65.5 61.5 22 47 7.9 600°/120 C <sub>a</sub> 289 96.5 83.5 72.5 17 49 2.35 550°/120 C <sub>a</sub> 325 109 97 86.5 13 39 0.7								



TABLE 7, PART I.—NICKEL CHROMIUM STEELS\* (TENSILE, HARDNESS AND IMPACT TESTS).—(Continued)

Key No.	Treatment	BHN	UTS	YP	PL	EL	RA	IS <sub>u</sub> †	Lit.
250	820° { 650° } Q <sub>o</sub> { 600° } 120 C <sub>a</sub> { 550° } Tp	255 296 323	85 96.5 108	73.5 84.5 97	69 74 86.5	22 18 9	54 47 23	7.2 2.6 1.0	
	900° C <sub>a</sub> 650°/2 h Q <sub>w</sub>	248	83	64	50.5	21	56	8.15	
251	1000° Q <sub>o</sub> Tp { Q <sub>w</sub> ... 650°/120 } C <sub>s</sub> ...	263 255	89 87	72.5 71	56.5 64.5	18 15	43 37	6.2 0.3	(80)
	900° Q { 675°/120 C <sub>a</sub> ... 650°/120 Q <sub>w</sub> ... 650°/120 C <sub>s</sub> ** 650°/360 C <sub>a</sub> ... 600°/120 C <sub>a</sub> ... 550°/120 C <sub>a</sub> ... } Tp	243 258 250 236 304 342	83.5 87 84 80 102 115.5	69 71 71 66.5 88 103	64.5 57 66 63 77 88	13 20 6 20 10 5	37 50 15 40 19 9	5.1 6.4 0.4 6.4 1.0 0.4	
	820° { 650° } Q <sub>o</sub> { 600° } 120 C <sub>a</sub> { 550° } Tp	255 300 338	84.5 100 114	73 87 103	68 80 91	20 10 6	46 25 19	5.4 1.1 0.7	
	F A 900°, 850° Q <sub>o</sub> Tp 660° C <sub>a</sub> ...	235	79	65	62	20	47	1.95	
252	1200° Q <sub>o</sub> Tp { Q <sub>w</sub> ... 650°/120 } C <sub>s</sub> ...	228 216	75.5 72.5	59.5 56	41 44	19 20	43 43	6.5 8.3	(51, 80)
	1000° Q <sub>o</sub> Tp { Q <sub>w</sub> ... 650°/120 } C <sub>s</sub> ...	200 195	64 63.5	46 47.5	31.5 36	24 23	63 63	7.6 3.05	
	900° { 650°/120 Q <sub>w</sub> ... 650°/120 C <sub>s</sub> ** 675°/120 C <sub>a</sub> ... 650°/360 C <sub>a</sub> ** 600°/120 C <sub>a</sub> ... } Tp	205 197 225 221 256	67 65 76.5 72.5 84	49 48.5 60.5 55 70	38 39.5 50.5 49 55	24 24 19 22 17	65 65 39 55 42	8.3 4.4 6.1 6.8 3.6	
	F A 815°, 625° C <sub>a</sub> 805° Q <sub>o</sub> Tp 680° C <sub>a</sub>	69 62.5	52.5 45	42.5 36	20 24	49 56	3.75 5.65		
253	900° Q <sub>o</sub> Tp { Q <sub>w</sub> ... 650°/120 } C <sub>s</sub> ...	250 245	83 81.5	66 64.5	53 53.5	21.5 21	55 51	4.9 0.6	(51)
	1000° Q <sub>o</sub> Tp { Q <sub>w</sub> ... 650°/120 } C <sub>s</sub> ...	259 250	85 82	68.5 66	53.5 35	20 20	49 51	4.6 0.6	
	1200° Q <sub>o</sub> Tp { Q <sub>w</sub> ... 650°/120 } C <sub>f</sub> ...	265 258						4.2 0.4	
254	820° C <sub>a</sub> ...	163††	56.5	33	12.3	32	65	11.8	(18, 62)
	820° Q <sub>o</sub> { 300° } 255 { 400° } 241 { 500° } 223 { 600° } 192 { 650° } 179	262 255 241 223 192 179	88 85 80 72.5 64.5 60	60? 60? 61.5 56.5 50.5 45.5	6.3 7.2 9.5 13.0 15.0 17.3	20 20 21 24 28 31	53 60 63 67 71 72	5.8 6.9 8.3 10.25 13.0 14.1	
	PL								
255	1200° Q <sub>o</sub> Tp { Q <sub>w</sub> ... 650°/120 } C <sub>s</sub> **...	208 199	70.5 68.5	52 52	34 39	19 21	47 45	6.35 5.25	(80)
	900° Q <sub>o</sub> Tp { Q <sub>w</sub> ... 650°/120 } C <sub>s</sub> **...	227 219	74 71	51 53	36 44	22 23	51 51	6.35 5.8	
	F 815° Q <sub>o</sub> Tp 650° C <sub>a</sub> F A 815°, 815° Q <sub>o</sub> Tp 650° C <sub>a</sub> ...	66.5	39.5	31.5	22	44		4.4	
256	v. Fig. 13								
257	825° { 600° } Q <sub>w</sub> { 650° } Q <sub>w</sub>	286 269	102 93	95.5 77.5		18.5 22	54 61	9.4 11.1	(28)
	845° { 600° } Q <sub>w</sub> { 650° } Q <sub>w</sub>	311 262	106.5 91.5	100 79		16.5 23	55 61.5	8.6 10.5	
258	1000° Q <sub>o</sub> Tp { Q <sub>w</sub> ... 650°/120 } C <sub>s</sub> **...	253 247	84.5 83.5	67 67	55 61.5	19 17	43 34	5.55 0.3	(80)
	900° { 675°/120 C <sub>a</sub> ... 650°/120 Q <sub>w</sub> ... 650°/120 C <sub>s</sub> ** 650°/360 C <sub>a</sub> ... 600°/120 C <sub>a</sub> ... 550°/120 C <sub>a</sub> ... } Tp	240 253 249 239 280 313	78.5 84.5 84 82 94 104.5	60 67.5 67.5 65.5 80 93	49 56.5 63 61.5 69.5 82	10 18 10 19 13 13	15 45 14 46 26 38	5.25 5.95 0.3 4.85 0.8 0.55	
	850° Q <sub>o</sub> 660°/2 h C <sub>a</sub> ...	80	63	55		19	42		
	820° Q <sub>o</sub> { 650° } C <sub>a</sub> Tp 2 h { 550° } C <sub>a</sub>	258 289 314	86.5 94.5 105	72 83 94.5	67.5 72.5 85	18 13 14	41 24 37	5.4 1.0 0.55	
	F A 900°, 850° Q <sub>o</sub> Tp 660° C <sub>a</sub> ...	237						1.95	

TABLE 7, PART I.—NICKEL CHROMIUM STEELS\* (TENSILE, HARDNESS AND IMPACT TESTS).—(Continued)

Key No.	Treatment	BHN	UTS	YP	PL	EL	RA	IS <sub>u</sub> †	Lit.
259	As received..... 950° C <sub>a</sub> ..... A 950°..... 850° Q <sub>o</sub> Tp { 250°... 300°... 350°... }	147.5 141 67.5 177 172 162.5	137 125 33 170 166 148			9.5 11 27 11 10 11	30.5 31 53 43.5 39 41		(71)
260	F 900° Q <sub>o</sub> Tp { Q <sub>w</sub> ... 650°/120 } C <sub>s</sub> ...	297 282	96.5 93.1	76 75.5	55 66	17 15	37 31	4.85 2.9	(51)
261	F 900° Q <sub>o</sub> Tp { Q <sub>w</sub> ... 650°/120 } C <sub>s</sub> ...	209 200	67.5 65	52.5 51	36 42.5	21 21	56 55	5.7 5.4	(51)
262a	850° C <sub>a</sub> .....	321	113	86.5		15	41	0.8	(4, 18, 47, 50, 51, 80, 109, 110)
b	N 820°.....	321	113	86.5		15	41	0.8	
c	200°.....	321	111.5	88		15	46	1.1	
d	300°.....	321	111	95.5		15	48	0.4	
e	400°.....	302	105.5	89.5		16	51	0.7	
f	500°.....	277	94.5	80		18	54	2.35	
g	600°.....	255	85	71		22	60	6.65	
h	650°.....	241	82	67.5		23	62	8.85	
i	790° C <sub>s</sub> **.....	167****	61.5	42		33	67	6.9	
j	1000° Q <sub>o</sub> Tp { Q <sub>w</sub> ... 670°/120 } C <sub>s</sub> ...	240 230	79 77	58.5 58	44 42.5	19 19	40 39	9.15 2.8	
l	1000° Q <sub>o</sub> Tp { Q <sub>w</sub> ... 650°/120 } C <sub>a</sub> ...	245 245 237	78 78 77	61 62.5 61.5	45.5 49 50	23 25 20	55 58 47	7.6 4.15 0.7	
m	(l) Tp <sub>2</sub> 650° C <sub>s</sub> **.....	235	75	59	49	22.5	52	0.7	
p	(n) Tp <sub>2</sub> 650° Q <sub>w</sub> .....	235	74	57	42.5	20	45	9.0	
q	900° Q <sub>o</sub> 675°/2 h C <sub>a</sub>	234	80	53	41	17	34	5.7	
r	900° Q <sub>o</sub> Tp { Q <sub>w</sub> ... 650°/120 } C <sub>s</sub> **...	245 240	81 80	64 63.5	46 53	21 23	54 58	6.1 1.1	
t	(r) Tp <sub>2</sub> 670° Q <sub>w</sub> .....	226	77	53.5	31.5	16.5	32	6.25	
u	900° Q <sub>o</sub> 650°/6 h C <sub>a</sub> ...	226	76	60	47	20	43	6.4	
v	900° Q <sub>o</sub> 600°/2 h C <sub>a</sub> ...	264	88	76	63	18	42	1.8	
w	900° Q <sub>o</sub> 550°/2 h C <sub>a</sub> ...	286	94	84.5	69	15	37	1.0	
x	850° Q <sub>o</sub> Tp { Q <sub>w</sub> ... 650° } C <sub>s</sub> **...	245 240	76.5 76	61 60.5	49 52	21 22.5	56 56	8.3 1.25	
y	850° Q <sub>w</sub> Tp { Q <sub>w</sub> ... 675°/495 } C <sub>s</sub> **...	230 220	73 71	49 48	30.5 33	24 25	48 52	9.0 5.1	
aa	820° Q <sub>o</sub> { 400° Q <sub>w</sub> ... 500° Q <sub>w</sub> ... 550° C <sub>a</sub> ... 600° Q <sub>w</sub> ... 600° C <sub>a</sub> ... 650° C <sub>a</sub> ... 650° C <sub>s</sub> **... } Tp 2 h	388 331 287 285 270 243 224	135 115 94 97.5 88 80.5 74	122.5 105.5 85 89 77 67.5 60		14 18 4 20 12 18 16	50 54 7 61 25 43 32	0.8 2.8 1.1 6.5 1.9 5.7 1.8	
bb	(hh) Tp <sub>2</sub> 650° Q <sub>o</sub> .....	218	72	57.5	47	19	49	5.95	
jj	820° Q <sub>o</sub> 705° { Q <sub>w</sub> ... 75 C <sub>a</sub> 600° } C <sub>s</sub> **...	220 217	75 74	53.5 50	31.5 31.5	21 21	50 43	5.1 2.2	
kk	820° Q <sub>o</sub> 705° { Q <sub>w</sub> ... 75 Q <sub>o</sub> 600° } C <sub>s</sub> **...	223 214	76.5 73.5	58 54.5	39.5 42.5	21 19	51 45	5.7 2.35	
ll	820° Q <sub>o</sub> 788° Q <sub>o</sub> { C <sub>s</sub> ... Tp <sub>2</sub> 650° } Q <sub>w</sub>	247 246	79.5 80	73 70.5	71.5    60.5¶¶¶	24 23	69 69		
nn	820° Q <sub>o</sub> 788° Q <sub>o</sub> { C <sub>s</sub> ... Tp <sub>2</sub> 650° } Q <sub>w</sub>	247 246	79.5 80	73 70.5	71.5    60.5¶¶¶	24 23	69 69		
oo	820° Q <sub>o</sub> 788° Q <sub>o</sub> { C <sub>s</sub> ... Tp <sub>2</sub> 650° } Q <sub>w</sub>	247 246	79.5 80	73 70.5	71.5    60.5¶¶¶	24 23	69 69		
pp	820° Q <sub>o</sub> 788° C <sub>s</sub> **.....		61.5	42	40	33	67		
263a	1000° { C <sub>s</sub> 0.3c°/m } 800°	229 209	78.5 72.5	45 41.5	30 34.5	22 27	51 61	2.8 5.8	(18, 28, 47, 50, 51, 65, 69, 71, 80, 109, 110)
c	1000° C <sub>a</sub> .....	296	99.5	63.5	16	16	41	1.8	
d	900° C <sub>a</sub> Tp { Q <sub>w</sub> ... 650°/120 } C <sub>a</sub> ...	220 217	74 73.5	55.5 56	41 45.5	25 25	66 66	9.4 9.4	
e	800° C <sub>a</sub> .....	296	100	64	20.5	18	43	2.35	
f	1000° Q <sub>o</sub> Tp { Q <sub>w</sub> ... 700°/120 } C <sub>s</sub> **...	267 237	90 78	50.5 50	23.5 20.5	19 26	47 62	6.1 9.4	
g	1000° Q <sub>o</sub> Tp { Q <sub>w</sub> ... 550°/120 } C <sub>s</sub> **...	310 311	99 100.5	88 88	71 67.5	20 15	56 28	6.35 1.8	
h	1000° Q <sub>o</sub> Tp { Q <sub>w</sub> ... 400°/120 } C <sub>s</sub> **...	401 397	134 133	123 123	82 74	12 8	41 22	0.8 0.8	
i	900° Q <sub>o</sub> 675°/2 h C <sub>a</sub> ...	242	82.5	54.5	33	24	55	6.25	
j	900° Q <sub>o</sub> Tp { Q <sub>w</sub> ... 650°/120 } C <sub>s</sub> **...	247 245	83 82.5	67 67	47 58	25 25	66 65	10.25 3.45	
k	900° Q <sub>o</sub> 650°/6 h C <sub>a</sub>	244	82	65.5	53.5	25	65	9.95	

TABLE 7, PART I.—NICKEL CHROMIUM STEELS\* (TENSILE, HARDNESS AND IMPACT TESTS).—(Continued)

Key No.	Treatment	BHN	UTS	YP	PL	EL	RA	IS <sub>u</sub> †	Lit.
263									
q	900° Q <sub>o</sub> 600°/2 h C <sub>a</sub>	262	90.5	77.5	66	23	66	7.9	
r	850° Q <sub>o</sub> { 530° } ***	321	110	100	90	18	54	3.6	
s	600° } Q <sub>w</sub> †††	275	98	88	74	21	62	6.8	
t	650° } †††	248	89	78	60.5	24	66	9.0	
u	820° Q <sub>o</sub> .....	495	182.5			14	37	1.5	
v	{ 200° }.....	469	168.5			14.5	50	2.8	
w	{ 300° }.....	436	152.5	126		14.5	53	0.55	
x	Same, 400° } Q <sub>w</sub>	388	134	118		16	54	1.1	
y	500° } Q <sub>w</sub>	331	112	102		19	56	3.9	
z	600° } Q <sub>w</sub>	285	94.5	85		22.5	62	8.15	
aa	650° } Q <sub>w</sub>	269	89.5	75.5		24	65	10.25	
bb	700° } Q <sub>w</sub>	240	85	51	25	18	45	5.0	
cc	700° C <sub>a</sub> **	236	78	50	33	20	37	9.55	
264	900° Q <sub>o</sub> Tp { Q <sub>w</sub> ...	247	81	67.5	53.5	26	70	8.6	(51)
	650°/120 { C <sub>a</sub> ** ...	234	78	64.5	56.5	26	69	5.0	
265	830° Q <sub>o</sub> .....		194	106.5	42				(3, 28, 71)
	{ 100° }.....		190.5	121.5	52				
	Same, Tp { 200° }.....		174	136	90				
	{ 300° }.....		158	129	111				
	{ 400° }.....		145	121	102				
	825° Q <sub>o</sub> Tp { 600° }.....	300	105	90		21.5	54.5	6.9	
	{ 650° }.....	293	104	87		19	47	7.5	
	845° Q <sub>o</sub> Tp { 600° }.....	300	105	93		19	54	7.3	
	{ 650° }.....	293	103	88.5		18	49	7.2	
267	850° C <sub>a</sub> .....	477	180.5	133	2.3	13	40	2.5	(18, 30, 62, 65, 71)
	820° C <sub>a</sub> .....	477§§§	176	139	2.3	10	39	2.35	
	{ 200° }.....	477	174.5	132	2.6	11	44	2.35	
	{ 300° }.....	444	162.5	128	2.0	12	48	1.65	
	Same, Tp { 400° }.....	418	141.5	126	2.1	14	52	1.95	
	{ 500° } Q <sub>w</sub>	351	116.5	105.5	3.7	18	56	4.7	
	{ 600° }.....	277	94.5	82	11.7	23	65	10.4	
	{ 650° }.....	262	85	72.5	14.6	25	67	11.5	
	820° { 400° } Q <sub>w</sub>	418	143	137	2.8	13	52	2.35	
	{ 500° }.....	364	123	112	5.8	16	56	5.1	
	{ 620° } Q <sub>w</sub>	269	ScH = 44						
	{ 650° }.....	262	90	74	13.8	24	57	11.9	
	A.....	255	ScH = 45						
268	W <sub>gf</sub> 795° C <sub>a</sub> .....	430	183	144.5	2.4	11	38	2.0	(28)
	W <sub>salt</sub> 795° C <sub>a</sub> .....	444	186	141	2.55	13	34	2.0	
	W <sub>gf</sub> 825° C <sub>a</sub> .....	430	183	143.5	2.65	12.5	39	2.15	
269	830° C <sub>a</sub> .....		173.5	103	38				(3)
	{ 100° }.....		161.0	109	55.5				
	{ 200° }.....		152.0	128	93.5				
	Same, Tp { 300° }.....		145.0	140.5	104				
	{ 400° }.....		132.5	115.5	91.5				
	{ 500° }.....		110.0	102.5	89				
	{ 600° }.....		95.5	75.5	61				
270	900° Q <sub>o</sub> Tp { Q <sub>w</sub> ...	245	81	58	36	24	62	8.2	(28, 51)
	650°/120 { C <sub>f</sub> ** ...	239	80	55	36	24	65	6.1	
271	As forged.....	279	80			7		IS <sub>y</sub> †	(136)
	1150° Q <sub>o</sub> .....		82	35		52		24.5	
273	1000° } Q <sub>o</sub> .....	237	83.5	49		22	37		(136)
	1100° } Q <sub>o</sub> .....	214	80	45.5		35	42.5		
	1200° } Q <sub>o</sub> .....	203	75	36.5		47	48.5		
274	1000° Q <sub>w</sub> .....		77	33		73	68	IS <sub>u</sub> †	(52)
275	As received, R.....	196	70	38		45 to 25	57 to 46	5.5	(71)
	950° C <sub>a</sub> .....		70	29		57	58		
	950° C <sub>f</sub> .....		63	27		48.5	51		
	900° Q <sub>w</sub> .....		74.5	30		62	59		
	As { 300° }.....		79	42		40.5	51		
	reel- { 400° } 60 Q <sub>w</sub>		80.5	49.5		35	51		
	ved, { 500° }.....		70.5	36.5		29.5	43		
	Tp { 600° }.....		61.5	37.5		28	44.5		
	Tp 400°/360 Q <sub>w</sub> .....		73	49.5		40	52		
	Tp 350°/120 Q <sub>w</sub> .....		74	39.5		47.5	52		
	900° Q <sub>w</sub> Tp 400°/60..		71.5	33		58	54		

TABLE 7, PART I.—NICKEL CHROMIUM STEELS\* (TENSILE, HARDNESS AND IMPACT TESTS).—(Continued)

Key No.	Treatment	BHN	UTS	YP	PL	EL	RA	IS <sub>w</sub> †	Lit.
276	BHN: 900° Q <sub>w</sub> = 187; 1000° Q <sub>w</sub> = 187; 1100° Q <sub>w</sub> = 293								(71)
277	950° Q <sub>w</sub> .....		75	45		30		7.5	(71)
278	As for service.....	ca. 160	Scleroscope hardness = ca. 19						(20)

\* See Table of Chemical Analyses, p. 486

† For meaning of subscripts, v. p. 396.

‡ PL = 23.5.

§ ScH = 40.

¶ Bars 3 in. diam.

\*\* C<sub>a</sub> = Cooled at 0.3° per min. between 600 and 400°.

†† ScH = 28.

‡‡ Large size Charpy test piece.

§§ ScH = 36; EL = 82.5.

|| ScH = 28; EL = 70.

¶¶ ScH = 29; EL = 60.5.

\*\*\* ScH = 50.

††† ScH = 45.

‡‡‡ ScH = 38.

§§§ ScH = 69.

|||| On 75 mm diam.

¶¶¶ 15 mm diam.

\*\*\*\* ScH = 22.

†††† Additional values of impact strength for steels Nos. 262 and 263.

KN	Trt	a	b	c	d	e	f	g	h	bb	cc	ee
262	IS <sub>v</sub>	1.3	1.2	1.3	0.6	0.8	2.4	6.1	10.1	1.1	2.5	6.9

Trt	l	m	n	o	p	Trt	j	k	l	m
IS <sub>v</sub>	7.6	2.5	0.55	0.4	7.1	IS <sub>x</sub>	12.0	5.0	11.0	5.3

Trt	n	o	p	r	s	t	x	y	z	aa	ee
IS <sub>x</sub>	0.8	0.6	9.8	7.8	2.5	8.9	10.2	1.8	12.0	7.6	6.3

Trt	jj	kk	ll	mm	Trt	nn	oo	pp	Nos. 262j to 262aa tested on the Guillery Mach.		
IS <sub>x</sub>	7.6	4.2	8.2	4.3	IS <sub>z</sub>	7.5	7.8	6.9			

KN	Trt	u	v	w	x	y	z	aa
263	IS <sub>v</sub>	1.6	2.9	0.7	1.7	3.5	8.9	12.8

TABLE 7, PART II.—COMPRESSION TESTS ON NI-CR STEELS

Key No.	Treatment	l, in.	Diam., in.	UCS	YPC	PLC	ELC	Lit.
243	Hot rolled.....	3.5	0.75	45	28	26.5		(128)
262	830° C <sub>a</sub> A 788°/30 C <sub>f</sub> ..	3	0.75		43	39.5		(109, 110)
	830° Q <sub>o</sub> 600° Q <sub>o</sub> .....	3	0.75	93.5	91.5	86	87	
	830° Q <sub>o</sub> 788° Q <sub>o</sub> { C <sub>f</sub>	3	0.75	70.5	70	68.7	69	
	650°/60 { Q <sub>w</sub>	3	0.75	70	68.5	64.5	64.5	
269	v. Fig. 40							

Specimens 0.564 in. × 0.564 in. diam. Loaded to 315 kg/mm<sup>2</sup> (28)

Key No.	257	257	263	263	265
Treatment.....	825° Q <sub>o</sub>	845° Q <sub>o</sub>	824° Q <sub>o</sub>	845° Q <sub>o</sub>	824° Q <sub>o</sub>
Permanent set...	23%	25%	12.7%	10.2%	2.8%

TABLE 7, PART III.—TORSION TESTS ON NI-CR STEELS

Key No.	Treatment	USS*	TMR	YPS	PLS	ELS	Total twist	Lit.
243	R <sub>h</sub> (2 in. × ⅜ in. diam.).	32.5c	43.5	19.5	17			(128)
	R <sub>h</sub> (2 in. × ⅜ in. outside diam. × ½ in. inside diam.).....			17	16			
257	825° Q <sub>o</sub> Tp { 600° }.....	61.5c	82.5	64.5			884°	(28)
	{ 650° }.....	59.5c	79	50.5			886°	
	845° Q <sub>o</sub> Tp { 600° }.....	66.5c	89	67.5			1094°	
	{ 650° }.....	59c	79	50			1104°	
262	830° C <sub>a</sub> 788°/30 C <sub>f</sub> .....			25.5	24			(109, 110)
	830° Q <sub>o</sub> 788°/30 Q <sub>o</sub> 650° C <sub>f</sub> .....					44	44.5	
	Same, but 650° Q <sub>w</sub> .....					44	44	
	830° Q <sub>o</sub> 600° Q <sub>o</sub> .....			59.5	51	51.5		



TABLE 7, PART III.—TORSION TESTS ON NI-CR STEELS.—  
(Continued)

Key No.	Treatment	USS*	TMR	YPS	PLS	ELS	Total twist	Lit.
263	850° Q <sub>o</sub> Tp { 530° 600° 650° } Q <sub>w</sub> †	67.5 <sub>o</sub> 62.5 <sub>o</sub> 57.5 <sub>o</sub>	90.5 83 76.5	61.5 58.5 51			310° 440° 600°	(28, 65)
265	825° Q <sub>o</sub> Tp 650°.....	69.5 <sub>o</sub>	92.5	58.5			1050°	(28)
	845° Q <sub>o</sub> Tp { 600°..... 650°.....	70 <sub>o</sub> 65.5 <sub>o</sub>	93 87	66.5 58			954° 886°	
267	830° Q <sub>o</sub> Tp 620°.....	61.5 <sub>o</sub>	82.5	51.5			399°	(65)
	820° H <sub>a</sub> ‡	106 <sub>o</sub>	141	88			27°	

\* Subscript <sub>o</sub> calculated on assumption of uniform stress throughout section.

† Specimen 2¼ in. × ½ in. diam.

‡ Specimen 1¾ in. × ⅝ in. diam.

TABLE 8.—NI-CU STEELS\*

Key No.	Treatment	BHN	ScH	UTS	YP	PL	El	RA	Lit.
279	As cast.....	139		60.2	42.9		25	42.5	(84)
280	As received.....			67.7	37.1			57	(93)
281	As cast.....	149		64.5	43.0		28	47	(84)
282	As forged.....			99.0	69.0		11.5	18	(54)
283	800° C <sub>a</sub> .....	320	37	105.5	90.1	56.2	11†	27	(23)
	800° Q <sub>o</sub> Tp‡.....	546	57	220.3	192.2		7.5†	36.5	
284	As forged.....			104.8	79.9		11	24.5	(54)
285	As rolled.....	307		61.1	40.7		20.5	45	(58)
286	As forged.....			77.6	58.1		22	48	(54)
287	As forged.....			92.9	60.5		11.5	23	(54)
288	As rolled.....	300		54.5	36.5		25	54	(58)
289	780° C <sub>a</sub> .....	326	35	122.0	120.8	38.7	6†	15	(23)
	780° Q <sub>o</sub> Tp‡.....	550	60	142.1?		105.5			
290	760° C <sub>a</sub> .....	279	37	98.2	92.5	49.9	11.5†		(23)
	760° Q <sub>o</sub> Tp‡.....	642	70	176.9?		98.4	20†	1	
291	As forged.....			79.2	56.2		19	38	(54)
	850° Q <sub>w</sub> Tp 400°.....			§	88.6				
292	As rolled.....			62.4	39.1		20	47	(58)
293	As forged.....			90.1	56.0		12.5	17	(54)
294	As cast.....	166		70.3	53.8		20	33	(84)
295	800° C <sub>a</sub> .....	292	38	101.0	94.4	49.2	12†	38	(23)
	800° Q <sub>o</sub> Tp‡.....	555	63	230.5	196.1	130.7	4.5†	8	
296	780° C <sub>a</sub> .....	285	38	103.7	92.5	59.8	12†	45	(23)
	780° Q <sub>o</sub> Tp‡.....	578	68	209.4	183.8		1†	2	
297	As forged.....			88.9	56.7		14	28.5	(54)
298	As forged.....			70.7	49.5		18.5	33	(54)
	850° Q <sub>w</sub> Tp 400°.....			§	129.6				
299	780° C <sub>a</sub> .....	396	40	108.4		49.2	1†		(23)
	780° Q <sub>o</sub> Tp‡.....	530	52	176.9		98.4	1†	14	
300	As forged.....			93.6	93.6		1	0	(54)
301	As received.....			62.4	41.6	30.8	16.5	29	(132)
	Annealed.....			61.6	40.5	34.5	21.5	33	
	Tp <sub>o</sub> .....			70.3	49.2	43.2	19.5	36	
302	As rolled.....			81.0	50.9		22	51	(101)
	Annealed.....			75.4	44.8		25	48	
	815° Q <sub>o</sub> Tp { 425°..... 315°.....			121.3 140.6	108.3 130.1		13 12	49 46	
303	As received.....			85.1	60.8	35.6	3	5	(132)
	Annealed.....			83.7	58.0	46.9	14.5	39	
	Tp <sub>o</sub> .....			60.6		59.4	0	0	
304	As received.....			71.0	40.3		42.5	61.5	(31)
305	As received.....			67.5	36.4		42	54	(31)
306	As forged.....	16		49.9	34.6		22.5	62.5	(22)
	Annealed.....	17		44.3	28.3		30	64	
307	As received.....			53.1	44.7		28	65.5	(31)
308	As received.....			52.8	45.4		25.5	71.5	(31)
309	As forged.....	18		57.8	44.7		28	65	(22, 31)
	Annealed.....	21		61.6	50.1		24	60	
310	As received.....			106.1	84.4		8	16	(31)
311	As forged.....	22		59.0	50.9		25	54	(22)
	Annealed.....	24		75.5	63.9		19	49.5	
312	As forged.....	27		75.6	64.5		20	53	(22)
	Annealed.....	26		72.4	61.9		20	62.5	

TABLE 8.—NI-CU STEELS.\*—(Continued)

Key No.	Trt	ScH	UTS	YP	El	RA	Lit.
313	F	37	104.5	98.1	13	37	(22)
	A	33	105.4	101.1	16	52	
314	F	39	130.1	110.6	13	40.5	(22)
	A	33	106.4	102.5	12	39	
315	F	40	117.1	101.4	7	16.5	(22)
	A	34	106.5	103.1	10	38	
316	F	41	129.3	114.2	10	27	(22)
	A	33	107.5	96.8	11	40.5	
317	F	41	144.0	119.5	7.5	17.5	(22)
	A	38	114.0	91.2	10.5	16	
318	F	42	143.0	131.3	6	7	(22)
	A	42	108.9	89.0	4	1	

Key No.	Treatment	IS <sub>  </sub>
283	800° Q <sub>o</sub>	1.0
289	780° Q <sub>o</sub>	0.8
290	760° Q <sub>o</sub>	0.5
295	800° Q <sub>o</sub>	1.1
296	780° Q <sub>o</sub>	0.4
299	780° Q <sub>o</sub>	0.5

\* For analyses v. p. 486.

† Dimensions of test piece = 2 in. × 0.3 in. diam.

‡ Tp 175°/3 h.

§ Broke in thread.

|| Izod machine. Specimens 0.45 in. diam. Area of notch 0.12 in.<sup>2</sup> (23).TABLE 9.—NICKEL VANADIUM STEELS\* (TENSILE, HARDNESS AND  
IMPACT TESTS)

Key No.	Treatment	BHN	UTS	YP	PL	El†	RA	IS‡	Lit.
319	N 900° C <sub>s</sub> .....	170	60.3		44.6	20	70		(55)
	850° Q <sub>w</sub> .....	311	115.3		96.6	9	43.5	IS <sub>y</sub>	
320	N 900° C <sub>s</sub> .....	235	95.7		48.0	7	8	6	(55)
321	850° C <sub>a</sub> .....		89.5	64.4	40.0	15	32		(71)
	850° Q <sub>o</sub> Tp { 600°..... 700°.....	282 235	94.2 91.0	55.6 70.0		12 16	21.5 29		
v. Figs. 29 and 46. BHN = 600 (Q <sub>w</sub> ); 532 (Q <sub>o</sub> ); 269 (C <sub>a</sub> ); 255 (C <sub>m</sub> )									
322	N 900° C <sub>s</sub> .....	277	89.6		46.1	11	25.5	6	(55)
323	N 900° C <sub>s</sub> .....	187	66.3		55.2	21.5	57	31	(55)
	850° Q <sub>w</sub> .....	387	117.0		97.0	8	44	11	
324	N 900° C <sub>s</sub> .....	217	72.3		64.0	16	48	16	(55)
	850° Q <sub>w</sub> .....	269	137.0		132.2	4	16.5	6	
325	850° C <sub>a</sub> .....		101.5	70.0	44.7	11.5	16.5		(71)
	850° Q <sub>o</sub> Tp { 650°..... 700°.....	302 241	104.0 97.2	61.9 77.8	38.8	10	21.5 20		
v. Figs. 29 and 46. BHN = 600 (Q <sub>w</sub> ); 578 (Q <sub>o</sub> ); 285 (C <sub>a</sub> ); 265 (C <sub>m</sub> )									
326	N 900° C <sub>s</sub> .....	166	77.0 (EL = 56.2)		16	61	6		(56)
	850° Q <sub>w</sub> .....	375					3		
327	N 900° C <sub>s</sub> .....	255	96.2		55.4	5	8.5	5	(55)
328	N 900° C <sub>s</sub> .....	183	60.8		44.8	17.5	38	5	(55)
	850° Q <sub>w</sub> .....	156	54.9		40.3	18	40	9	
329	N 900° C <sub>s</sub> .....	235	84.8		54.8	7	12	5	(55)
330	N 950° C <sub>s</sub> .....	196	69.2 (EL = 52.0)		20	46	6		(56)
	850° Q <sub>w</sub> .....	460					2		
331	840° C <sub>a</sub> §.....	255	102.1	61.4	35.9	16	47	IS <sub>u  </sub>	(23)
	840° Q <sub>o</sub> Tp¶.....	**	202.8		91.4	9	37.5	1.2	
332	827° Q <sub>o</sub> Tp 205°.....	512††	205.8	157.9	119.5	0	3.5	1.2	(23)
333	800° C <sub>a</sub> .....	302††	97.7	72.5	58.3	19.5	48.5		(23)
	800° Q <sub>o</sub> Tp¶.....	627§§	241.3	194.2		5	8	0.8	
334	R ½ in. diam.....		107.3	79.1		17 <sub>a</sub>	36		(8)
	800° C <sub>a</sub> .....		85.6	72.9		22 <sub>a</sub>	51		
						10 <sub>c</sub>			
	R 3 × ⅜ in. plate.....		111.6	64.5	EL	{ 20 <sub>a</sub> }	12	IS <sub>y</sub>	
335	N 900° C <sub>s</sub> .....	183	73.0		57	19	44	8	(56)
	850° Q <sub>w</sub> .....	460	129.0		129	0	2	5	

TABLE 9.—NICKEL VANADIUM STEELS\* (TENSILE, HARDNESS AND IMPACT TESTS).—(Continued)

Key No.	Treatment	BHN	UTS	YP	PL	El†	RA	ISy‡	Lit.
336	N 900° C <sub>s</sub> .....	179	67.8		49.0	21	44	8	(56)
	850° Q <sub>w</sub> .....	402						3	
337	N 900° C <sub>s</sub> .....	192	76.0		57.6	18	48	10	(56)
	850° Q <sub>w</sub> .....	293	157.0		148	11	48	8	
338	N 900° C <sub>s</sub> .....	235	78.2		61.8	17.5	45	8	(56)
	850° Q <sub>w</sub> .....	321	151.2		144	10	46.5	5	
339	N 900° C <sub>s</sub> .....	166	61.0		49.0	24.5	44	20	(56)
	850° Q <sub>w</sub> .....	302	154.0		146	10	46	9	

\* For analyses v. p. 487.  
† Dimensions of test pieces; 100 mm × 13.8 mm diam. except for Nos. 331–333 where they are 2 in. × 0.300 in. diam. and for Nos. 321, 325, 334, dimensions 2 in. × 0.564 in. diam.  
‡ For meaning of subscripts v. p. 396.  
§ ScH = 38.  
|| Test piece 0.35 in. diam. Area of notch = 0.074 in.<sup>2</sup>  
¶ Tp 175°/180.  
\*\* ScH = 43.                      †† ScH = 26.  
†† ScH = 69.                     §§ ScH = 60.

TABLE 10.—VANADIUM STEELS (TENSILE, HARDNESS AND IMPACT TESTS)

Key No.	Treatment	Hard- ness ScH	UTS	YP	PL	El	RA	IS	Lit.
340	815° Q <sub>o</sub> .....	44	97.7	79.4		3			(53)
	870° Q <sub>o</sub> .....	55	137.2	118.2		4.5			
	925° Q <sub>o</sub> .....	58	142.0	121.0		7			
	Same, Tp {	540°	38	87.1	80.6	14			
		595°	37	83.3	74.1	15			
		650°	35	74.5	68.9	15			
		705°	32	61.9	53.6	18			
		760°	28	53.1	42.8	20			
341	R ¾ in.*.....	BHN	106.9	67.7		6.5 <sub>a</sub>	7		(8)
342	As received.....	166	60.0	52.8		24 <sub>a</sub>	70		(106, 107)
	900° C <sub>a</sub> .....	104	39.5	27.7		36 <sub>a</sub>	74.5		
	A 950° C <sub>f</sub> †.....	82	36.2	20.8		39 <sub>a</sub>	73		
	850° {	400° C <sub>a</sub>	116	42.6	28.9	33 <sub>a</sub>	79		
		500° C <sub>a</sub>	121	48.5	30.5	35.5 <sub>a</sub>	77.5		
343	Q <sub>w</sub> Tp {	700° C <sub>a</sub>	116	44.2	32.1	35 <sub>a</sub>	75		
	As received.....	143	63.7	46.4		23 <sub>a</sub>	55		(106, 107)
	900° C <sub>a</sub> .....	126	50.4	33.4		32 <sub>a</sub>	62		
	A 950° C <sub>f</sub> †.....	94	40.0	19.5		37.5 <sub>a</sub>	62		
344	850° {	400° C <sub>a</sub>	157	59.8	40.9	31.5 <sub>a</sub>	67		
		500° C <sub>a</sub>	159	61.8	41.5	29.5 <sub>a</sub>	66		
	Q <sub>w</sub> Tp {	700° C <sub>a</sub>	145	56.2	39.0	31 <sub>a</sub>	69		
	As cast.....	156	56.8	26.2	15.8	23.5	29.5	0.9	(95)
345	A 925° C <sub>f</sub> .....	152	55.9	28.1	22.5	27.5	43	2.1	
	925° C <sub>a</sub> .....	162	62.3	36.9	35.5	26.4	47	2.6	
346	As received.....		104.5	59.8		4.5 <sub>a</sub>	3.5		(106)
	900° C <sub>a</sub> .....		83.1	45.3		17 <sub>a</sub>	32		
	A 950° C <sub>f</sub> †.....		59.4	25.2		28 <sub>a</sub>	44.5		
	850° {	400° C <sub>a</sub>	146.4	119.6		4.5 <sub>a</sub>	9		
		500° C <sub>a</sub>	134.4	89.8		9.5 <sub>a</sub>	23		
347	Q <sub>w</sub> Tp {	700° C <sub>a</sub>	95.9	63.0		17 <sub>a</sub>	35		
	As received.....	252	93.7	61.4		10.5 <sub>a</sub>	17		(106, 107)
	900° C <sub>a</sub> .....	202	72.4	46.0		23 <sub>a</sub>	45.5		
	A 950° C <sub>f</sub> †.....	136	55.2	22.7		26 <sub>a</sub>	43		
348	850° {	400° C <sub>a</sub>	286	105.0	80.2	16.5 <sub>a</sub>	44.5		
		500° C <sub>a</sub>	266	95.6	74.0	18 <sub>a</sub>	51		
	Q <sub>w</sub> Tp {	700° C <sub>a</sub>	212	79.1	56.7	24.5 <sub>a</sub>	57.5		
	As received.....		109.9	61.4		9.5 <sub>a</sub>	18		(106)
349	900° C <sub>a</sub> .....		100.8	48.8		11.5 <sub>a</sub>	20.5		
	A 950° C <sub>f</sub> †.....		63.2	25.2		18 <sub>a</sub>	27.5		
	850° {	400° C <sub>a</sub>	146.4	112.0		11.5 <sub>a</sub>	33.5		
		500° C <sub>a</sub>	142.2	100.8		13 <sub>a</sub>	35.5		
	Q <sub>w</sub> Tp {	700° C <sub>a</sub>	95.0	66.1		19.5 <sub>a</sub>	44		
350	As received.....		110.8	69.3		13 <sub>a</sub>	23		(106)
	900° C <sub>a</sub> .....		86.1	47.2		19.5 <sub>a</sub>	32		
	A 950° C <sub>f</sub> †.....		65.2	26.7		20 <sub>a</sub>	28		

TABLE 10.—VANADIUM STEELS (TENSILE, HARDNESS AND IMPACT TESTS).—(Continued)

Key No.	Treatment	BHN	UTS	YP	PL	El	RA	IS <sub>y</sub>	Lit.
348	850° Q <sub>w</sub> Tp $\left\{ \begin{array}{l} 400^{\circ} \text{ C}_a \\ 500^{\circ} \text{ C}_a \\ 700^{\circ} \text{ C}_a \end{array} \right.$		131.0 125.2 88.8	103.9 90.7 64.5		14 <sub>a</sub> 16 <sub>a</sub> 21 <sub>a</sub>	41 39.5 50		
349	As received..... 900° C <sub>a</sub> ..... A 950° C <sub>f</sub> †.....  850° Q <sub>w</sub> Tp $\left\{ \begin{array}{l} 400^{\circ} \text{ C}_a \\ 500^{\circ} \text{ C}_a \\ 700^{\circ} \text{ C}_a \end{array} \right.$	228 196 120  236 227 195	84.5 66.8 48.5	61.4 45.8 25.8		18 <sub>a</sub> 23 <sub>a</sub> 32 <sub>a</sub>	41.5 48.5 39		(106, 107)
350	N 900° C <sub>s</sub> †..... 850° Q <sub>w</sub> .....	286 600	88.5 115.3		43.8 103.0	8 6	20 12	3 0	(55, 119)
351	R (bar)..... 800° C <sub>a</sub> .....  R 3 × $\frac{3}{8}$ in.....		75.4 57.1  69.7	58.9 44.4  53.1	36.9	23 <sub>a</sub> 29.5 <sub>a</sub> $\left\{ \begin{array}{l} 19_a \\ 31_c \end{array} \right.$	51 59.5  51.5		(8, 128)
352	N 900° C <sub>s</sub> †..... 850° Q <sub>w</sub> .....	140 156	43.8 54.6		30.2 49.2	24 22.5	62.5 66.5	30 10	(55, 119)
353	820° C <sub>a</sub> §..... 820° Q <sub>o</sub> Tp ¶.....	208   196**	75.3 81.1	55.7 67.0	49.9 59.7	22 12	52 45		(23)
354	R $\frac{1}{4}$ in.*.....		120.0	68.0		8.5 <sub>a</sub>	10		(8)
355	780° C <sub>a</sub> ..... 780° Q <sub>o</sub> Tp ¶.....	217†† 340§§	82.0 106.1	54.5	42.1 77.3	7.5 2.5	21 31		(23)
356	N 900° C <sub>s</sub> †..... 850° Q <sub>w</sub> .....	159 163	52.9 68.5		41.1 41.4	20 20	69 63	20 13	(55, 119)
357	R 3 × $\frac{3}{8}$ in.....		85.9	65.9		15 <sub>c</sub>	34.5		(8)
358	N 900° C <sub>s</sub> †..... 850° Q <sub>w</sub> .....	286 512	92.3 118.2		47.4 105.1	8 9	20 20	3 0	(55, 119)
359	R $\frac{1}{4}$ in.....		134.6	102.1		7 <sub>a</sub>	7.5		(8)
360	950°/6 h C 12 h		56.5	18.9		22 <sub>a</sub>	41.5		(9)
361	N 900° C <sub>s</sub> †..... 850° Q <sub>w</sub> .....	217 217	57.7 73.1		43.4 49.2	15.5 17.5	58 61	19 11	(55, 119)
362	N 900° C <sub>s</sub> †..... 850° Q <sub>w</sub> .....	332 555	96.2 130.1		56.2 112.2	4 3	19 10	4 0	(55, 119)
363	R $\frac{1}{4}$ in.*.....		132.2	92.6		7.5 <sub>a</sub>	9		(8)
364	R $\frac{3}{8}$ in.*.....		41.1	32.1		37 <sub>a</sub>	72		(8)
365	N 900° C <sub>s</sub> †..... 850° Q <sub>w</sub> .....	217 207	61.1 95.6		45.4 61.8	15 12	71 60	20 12	(55, 119)
366	R $\frac{3}{8}$ in.*.....		128.4	85.0		10 <sub>a</sub>	17.5		(8)
367	N 900° C <sub>s</sub> †..... 850° Q <sub>w</sub> .....	286 532	87.5 121.3		58.3 101.3	8 5	26 6.5	3 0	(55, 119)
368	N 900° C <sub>s</sub> †..... 850° Q <sub>w</sub> .....	159 156	56.4 71.7?		44.8 52.1	19 14	72.5 67	30 18	(55, 119)
369	N 900° C <sub>s</sub> ..... 850° Q <sub>w</sub> .....	262 321	94.9 112.2		64.1 101.1	9 13	31 13	3 3	(55, 119)
370	N 900° C <sub>s</sub> †..... 850° Q <sub>w</sub> .....	159 156	50.4 55.4		39.4 42.3	15 12	68 60	25 25	(55, 119)
371	950°/6 h C 12 h		55.1	22.1		24.5 <sub>a</sub>	52		(9)
372	N 900° C <sub>s</sub> ..... 850° Q <sub>w</sub> .....	286 652	91.4 105.3		48.1 75.6	9 11.5	34 18.5	2 0	(55, 119)
373	N 900° C <sub>s</sub> †..... 850° Q <sub>w</sub> .....	99  45.6	47.1  45.6		26.8 29.5	26 21	74 61	22	(55, 119)
374	N 900° C <sub>s</sub> †..... 850° Q <sub>w</sub> .....	262 321	85.2 99.7		58.2 67.7	16 3	28.5 6.5	3 0	(55, 119)
375	N 900° C <sub>s</sub> †..... 850° Q <sub>w</sub> .....	255 578	98.9 95.3		55.3 58.7	14 11	25 41	5 0	(55)
376	N 900° C <sub>s</sub> †..... 850° Q <sub>w</sub> .....	143 121	46.5 44.3		25.5 26.3	17 26.5	61 58.5	6 3	(55, 119)
377	950°/6 h C 12 h		52.6	26.8		25 <sub>a</sub>	53		(9)
378	N 900° C <sub>s</sub> †..... 850° Q <sub>w</sub> .....	109 99	43.8 42.5		24.8 25.9	30 30	63 65	2 3	(55, 119)
379	N 900° C <sub>s</sub> †..... 850° Q <sub>w</sub> .....	143 105	51.7 45.8		28.9 35.8	20 27.5	34 41	3 2	(55, 119)



TABLE 10.—VANADIUM STEELS (TENSILE, HARDNESS AND IMPACT TESTS).—(Continued)

Key No.	Treatment	BHN	UTS	YP	PL	El	RA	IS <sub>y</sub>	Lit.
380	N 900° C <sub>s</sub> †.....	118	46.5		25.3	31	53	4	(55,
	850° Q <sub>w</sub> .....	124	46.9		26.2	22	56	2	119)
381	N 900° C <sub>s</sub> †.....	179	62.5		31.6	12	37.5	0	(55,
	850° Q <sub>w</sub> .....	187	58.2		42.3	17.5	33	0	119)
382	950°/6 h C 12 h		53.1	23.6		23 <sub>a</sub>	31.5		(9)
383	Same.....		58.3	28.3		10 <sub>a</sub>	10		(9)

Compression test on No. 351 (hot rolled):

UCS = 71, YP<sub>C</sub> = 45, PL<sub>C</sub> = 38 kg/mm<sup>2</sup> (128).

\* Diameter.

† A 950°/18 h C<sub>f</sub>.

‡ Tensile specimen 100 mm × 13.8 mm diam.

§ Tensile specimen 2 in. × 0.300 in. diam.

|| ScH = 24.

¶ Tp 175°/3 h.

\*\* ScH = 27.

†† IS<sub>u</sub>: Specimen 10.09 mm diam., area at notch = 52.6 mm<sup>2</sup>.

‡‡ ScH = 22.

§§ ScH = 40.

||| IS<sub>u</sub>: Specimen 11.4 mm diam., area at notch = 77.8 mm<sup>2</sup>.

TABLE 10A.—SHEAR AND TORSION TESTS ON VANADIUM STEELS

Key No.....	350	352	358	361	362	365	367	368	369	372
USS.....	55.5	23	50.5	30	52	29	43	24	38	44
Key No.....	373	374	376	378	379	380	381	(N 900° C <sub>s</sub> )		
USS.....	24	40	24	24	27	27	31	Fremont machine used (119)		

Key No.	Treatment	USS	YPs	PLs	T <sub>w</sub>	Lit.	
344	As cast.....	40	16	11.5	697°	(95)	
	A 925° C <sub>f</sub> .....	44.5	24	21.5	694°		
	925° C <sub>a</sub> .....	48	27	24.5	1045°		
351	Hot rolled*,.....	56 <sub>c</sub> †	31.5	24		(128)	

\* 2 in. × 5/8 in. diam.

† Calculated on assumption of uniform stress throughout section.

TABLE 11.—ELASTIC PROPERTIES

Key No.	Treatment	10 <sup>-2</sup> E	10 <sup>-2</sup> G	Lit.
Carbon Steels				
1	Normalized.....		83	(90, 110)
	Annealed.....		79.5	
2	R <sub>b</sub> 14.3 mm*.....	190		(46)
	D { 13.0 mm.....	196		
	12.0 mm.....	192		
	10.8 mm.....	190		
	9.7 mm.....	187		
	R <sub>b</sub> 5.20 mm*.....	200		
	D { 3.97 mm.....	215		
	2.83 mm.....	210		
	2.37 mm.....	210		
	2.00 mm.....	200		
	1.70 mm.....	198		
	1.37 mm.....	200		
	1.18 mm.....	201		
	0.98 mm.....	200		
3	Forged.....	208	79†	(15, 34, 141)
	A 850°.....	206		
	850° Q <sub>w</sub> .....	211		
	850° Q <sub>o</sub> 80°.....	206		
	1000° Q <sub>w</sub> .....	207		
	Same, Tp 550°.....	207		
	1000° Q <sub>o</sub> .....	208		
5	Rolled.....	210		(123)
	A 670°/30.....	209		

TABLE 11.—ELASTIC PROPERTIES.—(Continued)

Key No.	Treatment	10 <sup>-2</sup> E	10 <sup>-2</sup> G	Lit.
Carbon Steels				
7	A 900°.....	206	82‡	(29, 74, 141)
	850° Q <sub>w</sub> .....	200		
	Same, Tp 550°.....	199		
	850° Q <sub>o</sub> 80°.....	206		
	Same, Tp 550°.....	200		
	900° Q <sub>o</sub> .....	199	82	
8	850° Q <sub>w</sub> .....	210		(141)
	Same, Tp { 550°.....	207		
	650°.....	207		
	850° Q <sub>o</sub> 80°.....	206		
	Same, Tp 550°.....	205		
13	R <sub>b</sub> 15.0 mm*.....	202		(46)
	D { 14.3 mm.....	198		
	13.8 mm.....	199		
	13.2 mm.....	200		
	12.7 mm.....	200		
	11.2 mm.....	201		
	8.2 mm.....	199		
14	A 760° C <sub>f</sub> .....	204	83	(140)
16	Rolled.....	218		(86, 123)
	A { 675°.....	{ 213	(v. also	
	1150°.....	{ 220	Fig. 23)	
	900°.....		82	
19	Annealed.....	204	82.7	(74, 110)
	N 815°.....		83	
	845° Q <sub>w</sub> 565° C <sub>a</sub> .....		84	
22	R <sub>b</sub> .....	198		(141)
	A 850°.....	199		
	850° Q <sub>w</sub> Tp 550°.....	197		
	850° Q <sub>o</sub> Tp 550°.....	198		
26	Forged.....	226		(15)
	Annealed.....	213		
	Hardened.....	211		
27	775° Q <sub>w</sub> 650° C <sub>f</sub> .....		85.5	(110)
32	N 845°.....		82	(46, 110)
	790° Q <sub>w</sub> Tp 650°.....		85	
	R <sub>b</sub> 5.37 mm*.....	205		
	D { 4.36 mm.....	202		
	3.60 mm.....	193		
	3.00 mm.....	208		
	2.48 mm.....	199		
	1.98 mm.....	200		
36	Forged.....	230		(15)
	Annealed.....	214		
	Hardened.....	208		
41	R <sub>b</sub> 15.0 mm*.....	209		(46, 141)
	D { 14.3 mm.....	207		
	13.9 mm.....	205		
	13.2 mm.....	205		
	12.7 mm.....	201		
	11.2 mm.....	200		
	750° Q <sub>w</sub> .....	205		
	Same, Tp 350°.....	214		
	750° Q <sub>o</sub> 80°.....	206		

TABLE 11.—ELASTIC PROPERTIES.—(Continued)

Key No.	Treatment	$10^{-2}E$	$10^{-2}G$	Lit.
Carbon Steels				
42	R <sub>h</sub> .....	209		(141)
	750° Q <sub>w</sub> .....	204		
	Same, Tp 350°.....	214		
	750° Q <sub>o</sub> 80°.....	204		
45	A 900°.....	200	82	(74)
	900° Q <sub>o</sub> .....	192	78	
51	A 850°.....	209		(46, 141)
	750° Q <sub>w</sub> Tp 650°.....	200		
	R <sub>h</sub> 5.30 mm*.....	219		
	D { 4.58 mm.....	212		
	4.22 mm.....	205		
	3.84 mm.....	197		
	3.43 mm.....	200		
56	A 900° (v. also Fig. 23)...		80.5	(86)
58	F.....	211		(15)
	A.....	217		
	H.....	203		
59	A 900°.....	206	82.7	(74)
	900° Q <sub>o</sub> .....	193	78.7	
60	R <sub>h</sub> .....	208		(110, 141)
	A 790° C <sub>t</sub> .....		83.5	
	A 850°.....	205		
	750° Q <sub>w</sub> .....	199		
	850° Q <sub>w</sub> .....	197		
	790° Q <sub>o</sub> Tp { 450°.....		84.0	
	650°.....		86.5	
61	R <sub>h</sub> 15.0 mm*.....	201		(46)
	D { 14.3 mm.....	199		
	13.9 mm.....	199		
	13.2 mm.....	200		
	12.7 mm.....	197		
	12.3 mm.....	198		
64	A 900°.....	204	83.8	(74)
	900° Q <sub>o</sub> .....	193	80.0	
68	F.....	200		(15, 74, 110, 141)
	A.....	209	83.5	
	N 860°.....		82.0	
	750° Q <sub>w</sub> .....	202		
	Same, Tp 650°.....	202		
	850° Q <sub>w</sub> Tp 650°.....	199		
	900° Q <sub>o</sub> .....	192	80.0	
	Same, Tp 460°.....		84.0	
70	A 760° C <sub>t</sub> .....	215	82.0	(140)
75	F.....	208		(15)
	A.....	200		
77	A 900°.....	201	79	(74)
	900° Q <sub>o</sub> .....	189	75	
78	F.....	206		(15)
	A.....	208		
80	F.....	213		(15)
	A.....	207		

\* Diameter.

† λ (obs.) = 0.314.

‡ λ (obs.) = 0.265–0.275.

TABLE 11.—ELASTIC PROPERTIES.—(Continued)

Key No.	Treatment	$10^{-2}E$	$10^{-2}G$	Lit.
Cast Iron				
100	As cast.....	83		(124)
102	A 770–840°.....	17.6		(63)
106	As cast.....	84.3–105.5	45–57.7	(21)
111	As cast.....	85		(21, 124)
114	As cast.....	64.5		(124)
118	As cast.....	71		(124)

TABLE 12.—SPECIFIC GRAVITY

For changes in volume due to tempering, see p. 477

Key No.	Treatment	$d_4^{20}$	Lit.
Carbon Steels			
3	Normalized.....	7.87	(15, 115)
	900° Q <sub>w</sub> .....	7.866	
4	Annealed.....	7.871	(15)
5	Cold worked.....	7.855	(19, 71, 103, 116)
	Same, Tp 600°.....	7.857	
	R <sub>h</sub> or 900° Q <sub>w</sub> .....	7.862	
	Normalized.....	7.874	
7	A or 850° Q <sub>w</sub> .....	7.861	(15)
8	N 1000°.....	7.856	(115)
	800–1000° Q <sub>w</sub> .....	7.849	
9	Annealed.....	7.858	(15)
	850° Q <sub>w</sub> .....	7.841	
10	Annealed.....	7.863	(15)
11	Annealed.....	7.854	(15)
13	Normalized.....	7.854	(71)
	850° Q <sub>o</sub> .....	7.842	
15	N 1000°.....	7.840	(115)
	750–1000° Q <sub>w</sub> .....	7.821	
16	Annealed.....	7.867	(15, 103)
	850–1000° Q <sub>w</sub> .....	7.836	
18	Annealed.....	7.834	(15)
19	Annealed.....	7.853	(15)
	850° Q <sub>w</sub> .....	7.831	
20	1000° Q <sub>w</sub> .....	7.840	(102)
	Same, Tp { 200°/4 h.....	7.850	
	450–600°.....	7.860	
21	N 1000°.....	7.839	(15, 96, 115)
	700° Q <sub>w</sub> .....	7.838	
	900° Q <sub>w</sub> .....	7.833	
	1000° Q <sub>w</sub> .....	7.822	
	Annealed.....	7.855	
24	N 1000°.....	7.837	(115)
	750–1000° Q <sub>w</sub> .....	7.789	
26	F or A.....	7.817	(15)
	800° Q <sub>w</sub> .....	7.786	
29	Annealed.....	7.857	(15)
32	Cold worked.....	7.799	(46)
	Same, annealed.....	7.824	
33	N 1000°.....	7.822	(115)
	750–1000° Q <sub>w</sub> .....	7.797	
34	Annealed.....	7.860	(15)
36	F or A.....	7.800	(15)
	800° Q <sub>w</sub> .....	7.757	



TABLE 12.—SPECIFIC GRAVITY.—(Continued)

Key No.	Treatment	$d_4^{20}$	Lit.
<b>Carbon Steels</b>			
37	Annealed.....	7.860	(15)
38	Hardened.....	7.81	(19)
39	Normalized.....	7.843	(115)
	750–1000° Q <sub>w</sub> .....	7.805	
41	Annealed.....	7.829	(15)
	850° Q <sub>w</sub> .....	7.777	
43	Annealed.....	7.854	(15)
45	850° Q <sub>w</sub> .....	7.789	(3, 71)
	R <sub>c</sub> greatly.....	7.830	
	Same, A 600° or N.....	7.836	
46	Normalized.....	7.843	(15, 103,
	Annealed.....	7.852	115)
	750° Q <sub>w</sub> .....	7.784	
	900–1000° Q <sub>w</sub> .....	7.776	
49	Annealed.....	7.851	(15)
51	Annealed.....	7.84	(15, 46)
	Cold worked.....	7.835	
53	Normalized.....	7.839	(19, 102,
	Annealed.....	7.849	115)
	750° Q <sub>w</sub> .....	7.765	
	1000° Q <sub>w</sub> .....	7.752	
56	765° Q <sub>w</sub> .....	7.74	(103)
	900–1000° Q <sub>w</sub> .....	7.73	
58	F or A.....	7.833	(15)
	800° Q <sub>w</sub> .....	7.749	
60	Annealed.....	7.82	(15, 115)
	850° Q <sub>w</sub> .....	7.75	
	1000° Q <sub>w</sub> .....	7.76	
62	Hardened.....	7.76	(19)
63	Annealed.....	7.840	(15)
65	Annealed.....	7.838	(15)
66	N 1000°.....	7.79	(115)
	750° Q <sub>w</sub> .....	7.71	
	1000° Q <sub>w</sub> .....	7.66	
67	Annealed.....	7.82	(103)
	765° Q <sub>w</sub> .....	7.76	
	900° Q <sub>w</sub> .....	7.71	
68	F or A.....	7.826	(15, 102)
	800° Q <sub>w</sub> .....	7.773	
	Same, Tp { 200°/4 h.....	7.783	
	600°/1 h.....	7.824	
	1000° Q <sub>o</sub> .....	7.821	
	Same, Tp { 200°/4 h.....	7.831	
	600°/1 h.....	7.832	
	1100° Q <sub>w</sub> .....	7.729	
	Same, Tp { 200°/4 h.....	7.759	
	600°/1 h.....	7.796	
69	Hardened.....	7.79	(19)
70	Hardened.....	7.75	(19)
73	Annealed.....	7.837	(15)
75	F or A.....	7.819	(15)
	800° Q <sub>w</sub> .....	7.740	
	Hardened*.....	7.718	
76	Annealed.....	7.831	(15)

TABLE 12.—SPECIFIC GRAVITY.—(Continued)

Key No.	Treatment	$d_4^{20}$	Lit.
78	As forged.....	7.82	(15, 71)
	Annealed.....	7.825	
	800° Q <sub>w</sub> .....	7.73	
79	Annealed.....	7.823	(15)
80	As forged.....	7.793	(15, 115)
	Annealed.....	7.803	
	750° Q <sub>w</sub> .....	7.439	
	1000° Q <sub>w</sub> .....	7.373	
83	Annealed.....	7.802	(15)
<b>Cast Iron</b>			
101	A 840–880°.....	7.6	(63)
102	A 770–840°.....	7.6	(63)
103	As cast.....	7.58–	(78)
		7.73	
106	As cast.....	7.03–	(21, 78)
		7.20	
<b>Chromium Steels</b>			
141	Heated to cherry red, and Q <sub>w</sub>	7.76	(19)
145		7.76	
169		7.70	
178	1000° Q <sub>o</sub> .....	7.73	(71)
	Same, Tp 820° Q <sub>w</sub> .....	7.73	
180	950° Q <sub>o</sub> Tp { 250° Q <sub>w</sub> .....	7.755	(71)
	750° Q <sub>w</sub> .....	7.77	
182	1000° Q <sub>o</sub> .....	7.68	(71)
	Same, Tp 820° Q <sub>w</sub> .....	7.70	
183	1000° Q <sub>o</sub> .....	7.72	(71)
	Same, Tp 820° Q <sub>w</sub> .....	7.74	
191	As received.....	7.60	(36)
<b>Chrome-Vanadium Steels</b>			
203	850° Q <sub>o</sub> .....	7.817	(71)
	Same, Tp 650° Q <sub>w</sub> .....	7.839	
<b>Copper Steels</b>			
230	Hardened.....	7.835	(19)
231	As rolled.....	7.87	(6)
236	Hardened.....	7.84	(19)
237	Hardened.....	7.85	(19)
239	Hardened.....	7.75	(19)
<b>Nickel-Chromium Steels</b>			
262	I†.....	7.846	(51)
	II†.....	7.846	
	I Tp 600° Q <sub>w</sub> †.....	7.849	
	II Tp 600° C <sub>f</sub> †.....	7.850	
263	830° Q <sub>o</sub> .....	7.83	(51, 71)
	Same, Tp 600°.....	7.85	
	I Q <sub>w</sub> 600° Q <sub>w</sub> , 600° C <sub>f</sub> †.....	7.8475	
	I C <sub>f</sub> 600° C <sub>f</sub> , 600° Q <sub>w</sub> †.....	7.8469	
	II Q <sub>w</sub> 600° Q <sub>w</sub> , 600° C <sub>f</sub> †.....	7.8470	
	II C <sub>f</sub> 600° C <sub>f</sub> , 600° Q <sub>w</sub> †.....	7.8466	
267	820° C <sub>a</sub> .....	7.82	(71)
	820° Q <sub>o</sub> 630° Q <sub>w</sub> .....	7.835	

\* From a very high temperature.

† I = 1000° Q<sub>o</sub> 650°/2 h Q<sub>w</sub>.II = 1000° Q<sub>o</sub> 650°/2 h C<sub>f</sub>.

TABLE 13.—THERMAL PROPERTIES

$C_0^{100}$  = mean specific heat between 0 and 100°C, joules g<sup>-1</sup>  
 $k_0^{100}$  = mean thermal conductivity between 0 and 100°C, joules cm<sup>-2</sup> sec<sup>-1</sup> (°C, cm<sup>-1</sup>)

Key No.	Treatment	$C_0^{100}$	$k_0^{100}$	Lit.
<b>Carbon Steels</b>				
1	A 778°..... Hardened..... Normalized...	0.475	0.598 0.577	(13, 19, 24)
3	As forged..... Annealed.....	0.473	0.598	(71, 73)
4	Normalized...		0.460	(13)
5	Annealed..... 900° Q <sub>w</sub> .....	0.477	0.431 0.422	(19, 129)
7	As forged..... Annealed..... 900° Q <sub>w</sub> .....	0.477 0.472	0.448 0.448	(73, 129)
13	As forged..... A 650° or N...	0.485 0.481		(73)
14	As forged..... A 900°..... 900° Q <sub>w</sub> .....		0.356 0.393 0.310	(129)
20	As forged.....	0.489		(73)
25	As forged..... A 900°..... 900° Q <sub>w</sub> .....		0.339 0.372 0.322	(129)
31	As forged..... Normalized... A 650°.....	0.494 0.485		(73)
37	As forged..... Annealed..... 900° Q <sub>w</sub> .....		0.419 0.439 0.315	(24, 129)
38	As forged..... Annealed..... Hardened....	0.498 0.489		(19, 73)
43	Annealed.....		0.431	(129)
46	As forged..... Normalized... Annealed.....	0.498 0.494		(73)
49	Annealed.....	0.393		(129)

TABLE 13.—THERMAL PROPERTIES.—  
(Continued)

Key No.	Treatment	$C_0^{100}$	$k_0^{100}$	Lit.
51	As forged..... Annealed.....		0.422 0.422	(129)
53	As forged..... Normalized... 750° Q <sub>w</sub> .....	0.506 0.498	0.431	(13, 19, 73)
57	As forged..... A 650° or N...	0.510 0.498		(73)
60	As forged..... Annealed..... 830° Q <sub>w</sub> , 0°...		0.393 0.402 0.201	(24, 129)
62	Hardened....	0.510		(73)
64	As forged..... Annealed.....	0.510 0.502	0.381	(73, 129)
66	As forged..... A 650°.....	0.515 0.498		(73)
68	As forged..... A 960°, C <sub>f</sub> 24h 830° Q <sub>w</sub> , 0°...	0.515	0.435 0.184	(24, 73)
69	Normalized... Hardened....		0.410 0.515	(13, 19)
70	Normalized... Hardened....		0.343 0.510	(13, 19)
73	Annealed.....		0.356	(129)
74	As forged..... A 650°.....	0.515 0.502		(73)
78	As forged..... Annealed.....	0.510 0.510	0.347	(73, 129)
<b>Cast Iron</b>				
109	As east..... A 650°/24 h...	0.548 0.544		(73)
111	As east.....		0.623	(85)
113	As cast..... A { 5 min 0.560 10 min 0.552 670° { 60 min 0.485	0.573		(73)
119	As east..... A 650°/24 h...	0.581 0.573		(73)
<b>Chromium Steels</b>				
123	A 900°..... H 1100°.....		0.414 0.372	(100)

TABLE 13.—THERMAL PROPERTIES.—  
(Continued)

Key No.	Treatment	$C_0^{100}$	$k_0^{100}$	Lit.
129	A 900°..... H 1100°.....		0.402 0.368	(100)
140	A 900°..... H 1100°.....		0.397 0.364	(100)
141	W CR Q <sub>w</sub> ..... C <sub>a</sub> .....	0.540		(19)
145	W CR Q <sub>w</sub> .....	0.540		(19)
146	A 900°..... H 1100°.....		0.372 0.238	(100)
153	A 900°..... H 1100°.....		0.305 0.184	(100)
169	W CR Q <sub>w</sub> .....	0.502		(19)
170	A 900°..... H 1100°.....		0.218 0.163	(100)
178	1000° Q <sub>o</sub> ..... Same, T <sub>p</sub> 820° Q <sub>w</sub> .....		0.184 0.481 0.197	(71)
180	950° { 250° Q <sub>w</sub> Q <sub>o</sub> { 750° Q <sub>w</sub>		0.167 0.494 0.192	(71)
182	1000° Q <sub>o</sub> ..... Same, T <sub>p</sub> 820° Q <sub>w</sub> .....		0.130 0.489 0.180	(71)
183	1000° Q <sub>o</sub> ..... Same, T <sub>p</sub> 820° Q <sub>w</sub> .....	0.481	0.130 0.506 0.151	(71)
<b>Copper Steels</b>				
230	Hardened.... Air cooled....	0.535		(13, 19)
236	Hardened.... Air cooled....	0.535		(13, 19)
237	Hardened....	0.531		(19)
239	Hardened....	0.489		(19)
<b>Nickel Chromium Steels</b>				
266	A 718°..... Same, W 830° Q <sub>w</sub> , 6°.....		0.251 0.222	(24)
276	1000° Q <sub>w</sub> .....		0.117	(71)
278	As received...	0.514	0.105	(20)

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## MN-, SI-, AND MN-SI-STEELS; FE-SI-ALLOYS; AND EFFECT OF MN AND SI ON CAST IRON

ROBERT A. HADFIELD

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TABLE 1.—TENSILE, HARDNESS, AND IMPACT TESTS ON ROLLED AND FORGED MN-STEELS\*

Composition, hundredths of %					Treatment, v. p. 392	10 × UTS	10 × $\begin{cases} Y = YP \\ E = EL \\ P = PL \end{cases}$	10 × El†	10 × RA	Lit.‡
Mn	C	Si	P	S						
C < 0.3 %										
39	8	0.5	1.0	3.4	F, A 750°/3 h C <sub>z</sub> .....	346		365	720	(29)
48	8	0.8	0.7	1.6		358		360	720	(29)
50	12	0.8	2.7	3.0		386		330	620	(29)
58§	13	0.6	2.7	3.7		402		320	640	(29)
58§	14	0.9	2.6	3.5		436		300	610	(29)
60	8	0.6	2.6	4.3		367		350	700	(29)
69§	13	0.9	3.1	2.4		424		320	680	(29)
83§	20	3			F.....	528	339 E	315	457	(14, 17)
110§	<10	<21	<7	<4	R, A 860°  .....	386¶	299 Y	435	797	(2)
129§	10	37	2	2	F, N 1000°.....	507	358 E	350	650	(1)
130	7.3				F.....	425	282 E	IS = 39.0**		(10)
170§	10.4				F.....	498	287 E	IS = 36.0**		(10)
210§	23.6				F.....	558	408 E	IS = 28.1**		(10)
313	<10	<21	<7	<4	R, A 860°  .....	652¶	545 Y	250	632	(2)
410	<10	<21	<7	<4	R, A 860°  .....	842¶	324 Y	250	424	(2)
540	15	3.7			F, WY Q <sub>w</sub> .....	622		50	0	(13)
550	<10	<21	<7	<4	R, A 860°  .....	1040¶	610 Y	285	381	(2)
560	27.6				F.....	720	720 E	IS = 3.05**		(10)
588	3	11	<3	<5	{ F, A 926°/15..... Same, W <sub>2</sub> 955° Q <sub>w</sub> ††....	808	458 P	13	13	(30)
						1008	617 P	121	420	
610	3.4				F.....	1183	843 E	IS = 3.05**		(10)
861	4	16	<3	<5	{ F, A 926°/15..... Same, W <sub>2</sub> 955° Q <sub>w</sub> ††....	1059	618 P	17	26	(30)
						1074	696 P	20	33	
887	81	22	<3	<5	F, A 870°/15, W <sub>2</sub> 900° Q <sub>w</sub> ††.....	651	298 P	121	202	(30)
1050	<10	<21	<7	<4	R, A 860°  .....	912¶	485 Y	10	0	(2)
1290	<10	<21	<7	<4	R, A 860°  .....	884¶	312 Y	65	46	(2)
1290	15.6				F.....	650	299 E	IS = 12**		(10)
1570	<10	<21	<7	<4	F, A 860°  .....	1004¶	596 Y	175	206	(2)
1635	5	38	<3	<5	{ F, A 927°..... Same, W <sub>2</sub> 955° Q <sub>w</sub> ††....	736	198 P	166	135	(30)
						840	239 P	400	495	
1985	<10	<21	<7	<4	R, A 860°  .....	866	351 Y	300	335	(2)
3350	29.6				F.....	614	342 E	IS = 28.1**		(10)
C, 0.3–0.6 %										
98	50	9.4	9.8	8	{ F, W 659° Q <sub>w</sub> ..... F, W 700° Q <sub>w</sub> .....	753	471 E	152	502	(6)
v. also Figs. 1 and 2							878	443 E		85
230§	40	15			F.....	890		65	70	(14, 17)
358	45	5	<3	<5	{ F, A 870°/15..... Same, W <sub>2</sub> 816° Q <sub>o</sub> ††....	865	438 P	204	443	(30)
						1104	954 P	170	466	



TABLE 1.—TENSILE, HARDNESS, AND IMPACT TESTS ON ROLLED AND FORGED MN-STEELS.\*—(Continued)

Composition, hundredths of %					Treatment, v. p. 392	10 × UTS	10 × $\begin{cases} Y = YP \\ E = EL \\ P = PL \end{cases}$	10 × El†	10 × RA	Lit.‡
Mn	C	Si	P	S						
389	40	9			F.....	598		5		(14, 17)
872	48	8	<3	<5	$\begin{cases} \text{F, A } 870^{\circ}/15..... \\ \text{Same, W}_2 \text{ 900}^{\circ} \text{ Q}_w \dagger\dagger.... \end{cases}$	$\begin{matrix} 900 \\ 520 \end{matrix}$	$\begin{matrix} 274 \text{ P} \\ 260 \text{ P} \end{matrix}$	$\begin{matrix} 17 \\ 17 \end{matrix}$	$\begin{matrix} 26 \\ 20 \end{matrix}$	(30)
1439	46	10	<3	<5	$\begin{cases} \text{F, A } 870^{\circ}/15..... \\ \text{Same, W}_2 \text{ 900}^{\circ} \text{ Q}_w \dagger\dagger.... \end{cases}$	$\begin{matrix} 710 \\ 770 \end{matrix}$	$\begin{matrix} 219 \text{ P} \\ 219 \text{ P} \end{matrix}$	$\begin{matrix} 163 \\ 183 \end{matrix}$	$\begin{matrix} 190 \\ 226 \end{matrix}$	(30)
C, 0.6–0.9%										
41	78	6	2	3	R, A 860°  .....	672	425 Y	150	205	(3)
50	87.3				F.....	1150	595 E	IS = 3.05**		(10)
83	78	8	2	4	R, A 860°  .....	778	548 Y	150	160	(3)
116	85	9	2	4	R, A 860°  .....	832 ¶	406 Y	105	117	(2)
186	78	16	<3	<5	$\begin{cases} \text{F, A } 870^{\circ}/15..... \\ \text{Same, W}_2 \text{ 788}^{\circ} \dagger\dagger \ddagger\dagger.... \end{cases}$	$\begin{matrix} 906 \\ 1195 \end{matrix}$	$\begin{matrix} 378 \text{ P} \\ 1014 \text{ P} \end{matrix}$	$\begin{matrix} 108 \\ 142 \end{matrix}$	$\begin{matrix} 135 \\ 333 \end{matrix}$	(30)
200	80.4				F.....	1054	791 E	IS = 3.05**		(10)
221	86	11	2	3	R, A 860°  .....	901	476 Y	80	107	(3)
310	85	13	2	2	R, A 860°  .....	939 ¶	622 Y	50	52	(2)
385	81	9	2	2	R, A 860°  .....	753	533 Y	20	21	(3)
440	78	18	<3	<5	$\begin{cases} \text{F, A } 870^{\circ}/15..... \\ \text{Same, W}_2 \text{ 788}^{\circ} \dagger\dagger \ddagger\dagger.... \end{cases}$	$\begin{matrix} 980 \\ 1252 \end{matrix}$	$\begin{matrix} 417 \text{ P} \\ 894 \text{ P} \end{matrix}$	$\begin{matrix} 54 \\ 33 \end{matrix}$	$\begin{matrix} 66 \\ 40 \end{matrix}$	(30)
498	87	18	2	2	R, A 860°  .....	860 ¶	535 Y	20	20	(2)
510	76.2				F.....	866	602 E			(9)
720	70				F.....	566	414 E	IS = 10**		(10)
937	61	30	7	7	F.....	514	394 E	55		(14, 17)
1229	85	37	9	6	F.....	619	440 E	35	80	(14, 17)
1511	82	19	5	3	R, A 860°  .....	786 ¶	441 Y	5	7	(2)
C > 0.9%										
300	93.4				F.....	1010	827 E	IS = 3.05**		(10)
462	120	31	<3	<5	$\begin{cases} \text{F, A } 870^{\circ}/15..... \\ \text{Same, W}_2 \text{ 900}^{\circ} \text{ Q}_w \dagger\dagger.... \end{cases}$	$\begin{matrix} 910 \\ 473 \end{matrix}$	$\begin{matrix} 378 \text{ P} \\ 298 \text{ P} \end{matrix}$	$\begin{matrix} 46 \\ 33 \end{matrix}$	$\begin{matrix} 53 \\ 85 \end{matrix}$	(30)
868	127	19	<3	<5	$\begin{cases} \text{F, A } 870^{\circ}/15..... \\ \text{Same, W}_2 \text{ 900}^{\circ} \text{ Q}_w \dagger\dagger.... \end{cases}$	$\begin{matrix} 1234 \\ 677 \end{matrix}$	$\begin{matrix} 676 \text{ P} \\ 318 \text{ P} \end{matrix}$	$\begin{matrix} 13 \\ 79 \end{matrix}$	$\begin{matrix} 13 \\ 141 \end{matrix}$	(30)
1007§	95	17	4	3	R, A 860°  .....	665 ¶	474 Y	10	14	(2)
1121§	100	19	4	3	R, A 860°  .....	703	547 Y	10	8	(3)
1200§	96				F.....	896	618 E	IS = 28.1**		(10)
1268§	94	14	<3	<5	$\begin{cases} \text{F, A } 870^{\circ}/15..... \\ \text{Same, W}_2 \text{ 900}^{\circ} \text{ Q}_w \dagger\dagger.... \end{cases}$	$\begin{matrix} 786 \\ 1024 \end{matrix}$	$\begin{matrix} 240 \text{ Y} \\ 318 \text{ Y} \end{matrix}$	$\begin{matrix} 17 \\ 471 \end{matrix}$	$\begin{matrix} 27 \\ 392 \end{matrix}$	(30)
1338§	107	27	4	2	R, A 860°.....	730	438 Y	30	31	(3)
1522	150	14			$\begin{cases} \text{F}..... \\ \text{F, WW } \text{Q}_w..... \\ \text{F, WW } \text{C}_a..... \\ \text{Same}..... \end{cases}$	$\begin{matrix} 693 \\ 701 \\ 622 \\ 638 \end{matrix}$		$\begin{matrix} 10 \\ 120 \\ 10 \\ 40 \end{matrix}$		(13)
1959	93	21	7	3	R, A 860°  .....	822 ¶	389 Y	235	195	(2)

\* v. also Tables 2–6.

† Dimensions of test pieces: (1, 2, 3) 2 in. × 0.564 in. diam.; (6) 8 in. × 0.5 in. diam.; (3, 10) not stated; (13) 2 in. × 0.798 in. diam.; (14, 17) 8 in. × 0.75 in. diam.; (29) 10 cm × 2 cm diam.; (30) 1.2 in. × 0.30 in.

‡ See also (16, 18, 19, 27, 34).

§ Steels of commercial importance.

|| R, A 860°/36 h C 3 days.

¶ Brinell hardness number given in this table: (Treatment = 1000° Q<sub>w</sub>).

Mn	C	BHN	Mn	C	BHN	Mn	C	BHN
110	<10	143	1290	<10	302	498	87	286
313	<10	430	1570	<10	192	1511	82	196
410	<10	418	1985	<10	235	1007	95	179
550	<10	418	1160	85	650	1959	93	192
1050	<10	444	310	85	600			

\*\* Impact test on Fremont machine.

†† For 30 min.

‡‡ Q<sub>o</sub> W<sub>3</sub> 594°/30 C<sub>a</sub>.

TABLE 2.—EFFECT OF COOLING MEDIUM ON PROPERTIES OF FORGED MN-STEEL (14, 17)

Test pieces, 8 in.  $\times$   $\frac{3}{4}$  in. diam.

Treatment						F		F, WY Q <sub>w</sub>		F, WY Q <sub>o</sub>		F, WY C <sub>a</sub>	
Hundredths of %						10 $\times$ UTS	10 $\times$ EL	10 $\times$ UTS	10 $\times$ EL	10 $\times$ UTS	10 $\times$ EL	10 $\times$ UTS	10 $\times$ EL
Mn	C	Si	P	S									
695	52	37	8	7		400	15	365	16	296	16	332	23
722	47	44				432	16	387	16	392	31	421	47
790	50	28								466	70	447	78
937	61	30	7	7		514	55	613	148	602	148	594	156
1060	85	28				529	39	644	172	663	188	644	172
1401*	85	25				573	16	1057	444	865	266	755	141
915	100	42								665	172		
1011*	95	21				605	55			646	195	619	141
1260*	110	16				619	23	849	273	792	281	584	109
1281*	92	42				616	55	958	367	908	328	761	195
1998	190	32								359	Nil		
2169	210	46				567	86			525	109	531	117

Treatment						F		F, WY Q <sub>w</sub>		F, WY C <sub>a</sub>	
Hundredths of %						10 $\times$ UTS	10 $\times$ EL	10 $\times$ UTS	10 $\times$ EL	10 $\times$ UTS	10 $\times$ EL
Mn	C	Si									
1448*	110	32				620	509	8	999	353	375
1506	124	16				776	514	23	954	351	312
1840	154	16				807	509	8	838	367	101
1855	183	26				669	559	4	875	399	54
1910	160	26				811	558	8	922	558	46

\* Steels of commercial importance.

TABLE 3.—EFFECT OF LIQUID AIR TEMPERATURE ON FORGED MN-STEELS (13)

Hundredths of %			Treatment, v. p. 392	Tensile tests*				Mn, 12.64; C, 1.23 (1048° Q <sub>w</sub> )	
Mn	C	Si		At ca. 20°C		At -182°C†		p, atm.	BHN at ca. 20°C
				UTS	El	UTS	El		
350	8	13	{ 1102° C <sub>a</sub> 777° C <sub>f</sub> .. Same. Q <sub>a</sub> .....	104	7.5	139	Nil	10	194
540	15	3.7		109	9			20	191
1008	16	63	1048° Q <sub>w</sub> .....	104	Nil	96	Nil	40	205
1527	15		1048° Q <sub>w</sub> .....	93	1	82	Nil		
223‡	41	7	1048° Q <sub>w</sub> .....	61	5	72	2.5	p, atm.	BHN† at -182°C
381	78		1102° C <sub>a</sub> 777° C <sub>f</sub> ...	80	17	106	2.5	10	341
468	36	10	1102° C <sub>a</sub> 777° C <sub>f</sub> ...	104	10	118	Nil	20	363
700	100		Same, W <sub>2</sub> 614° C <sub>f</sub> ...	117	10	129	Nil	40	372
1153	166		1048° Q <sub>w</sub> .....	66	15	84	Nil		
			1048° Q <sub>w</sub> .....	88	10	120	2.5		
1264‡	123	{	994° Q <sub>w</sub> .....	102	40	101	Nil		
			1048° Q <sub>w</sub> .....	88	30	96	2.5		
			620° Q <sub>a</sub> .....	88	1.3				
			831° Q <sub>a</sub> .....	91	11				
			994° Q <sub>a</sub> .....	104	38				
1522	150	14	1048° Q <sub>w</sub> .....	93	25	101	2.5		

\* Test bars, 2.00 in.  $\times$  0.180 in. diam.

† Tests carried out in liquid air.

‡ Steels of commercial importance.

TABLE 4.—COMPRESSION TESTS ON FORGED MN-STEELS (17)\*

Composition, hundredths of %					Treatment	ELC	-100 $\frac{\Delta l}{l_0}$
Mn	C	Si	P	S			
937	61	31	7	7	F	39.5	20.10
1229	85	37	9	6	F, WY Q <sub>w</sub>	53.5	17.05
1375	85	23	9	8	F, WY Q <sub>w</sub>	70	16.65

\* v. also (1, 18).

† Reduction in length due to applied stress of 157.5 kg/mm<sup>2</sup>.

TABLE 5.—TENSILE PROPERTIES AND HARDNESS OF CAST MN-STEEL (22)\*

Treatments:  $\alpha$  = G;  $\beta$  = G, A 900°/60;  $\gamma$  = G, A 900°/60 Q<sub>w</sub> 15°.

No. and Trt		10 $\times$ UTS	10 $\times$ YP	10 $\times$ EL	10 $\times$ RA	BHN
1	$\alpha$ .....	439	325	279	535	119
	$\beta$ .....	400	304	315	700	113
	$\gamma$ .....	554	302	196	610	147
2	$\alpha$ .....	457	335	292	625	115
	$\beta$ .....	405	307	305	668	116
	$\gamma$ .....	580	324	192	620	165
3†	$\alpha$ .....	466	350	294	639	115
	$\beta$ .....	418	312	303	700	115
	$\gamma$ .....	592	342	160	622	154
4†	$\alpha$ .....	454	347	279	659	119
	$\beta$ .....	421	317	303	701	118
	$\gamma$ .....	594	350	141	561	157
5†	$\alpha$ .....	479	362	287	642	123
	$\beta$ .....	430	320	308	718	123
	$\gamma$ .....	680	350	155	530	179
6†	$\alpha$ .....	503	383	279	681	132
	$\beta$ .....	457	328	302	726	132
	$\gamma$ .....	758	443	152	482	230
7†	$\alpha$ .....	503	380	280	677	134
	$\beta$ .....	463	335	298	703	135
	$\gamma$ .....	783	465	163	478	237
8†	$\alpha$ .....	580	408	259	547	156
	$\beta$ .....	520	340	274	723	159
	$\gamma$ .....	1090	603	90	446	274
9†	$\alpha$ .....	597	411	260	468	162
	$\beta$ .....	551	347	262	667	165
	$\gamma$ .....	1106	627	67	417	289
10	$\alpha$ .....	652	428	212	434	197
	$\beta$ .....	647	351	188	606	198
	$\gamma$ .....	1158	639	49	266	326
11	$\alpha$ .....	725	446	188	394	211
	$\beta$ .....	761	367	154	531	218
	$\gamma$ .....	1171	649	31	189	

No.	Thousandths of %				
	Mn	C	Si	P	S
1	285	109	319	63	46
2	440	125	286	67	50
3†	675	126	303	67	46
4†	785	99	311	40	52
5†	1020	98	316	41	49
6†	1270	100	313	99	45
7†	1315	101	303	102	47
8†	1765	102	309	103	56
9†	1835	99	324	108	59
10	2230	90	301	102	58
11	2470	92	294	110	51

\* Specimens 20 cm  $\times$  2 cm diam.

† Steels of commercial importance.

TABLE 6.—TRANSVERSE TESTS ON CAST MN-STEEL\* (17); cf. (18)

Composition, hundredths of %					BMR
Mn	C	Si	P	S	
32	15	1	9	11	49
76	23	4	9	7	84
231	40	15	7	7	122

\* Test bars  $2\frac{3}{8}$  in. square, loaded at center, bearings 2 ft. apart.



TABLE 6.—TRANSVERSE TESTS ON CAST MN-STEEL\* (17); cf. (18)  
(Continued)

Composition, hundredths of %					BMR
Mn	C	Si	P	S	
389	55	9	6	7	18
643	34	30	11	11	30
695	52	37	8	7	54
830	62	35	10	4	71
1476	115	25	12	7	72
1762	140	91	10	6	92.5
2345	215	65	9	2	106.5

\* Test bars 2½ in. square, loaded at center, bearings 2 ft. apart.

TABLE 8.—SPECIFIC GRAVITY OF PURE Fe-Si-ALLOYS (28); v. also  
(9, 15, 21)

Prepared from pure soft wrought Fe and pure Fe-Si, only very small amounts of impurities present. Determination by pycnometer.

Si, %	$d_4^{20}$	Si, %	$d_4^{20}$	Si, %	$d_4^{20}$
0.2	7.883	24.8	6.432	65.9	3.367
2.0	7.784	27.2	6.248	79.4	2.787
7.5	7.352	29.3	6.198	93.4	2.363
15.0	7.032	40.2	5.378	95.0	2.322
20.0	6.696	46.8	4.876	100.0	2.309
21.9	6.546	51.8	4.406		

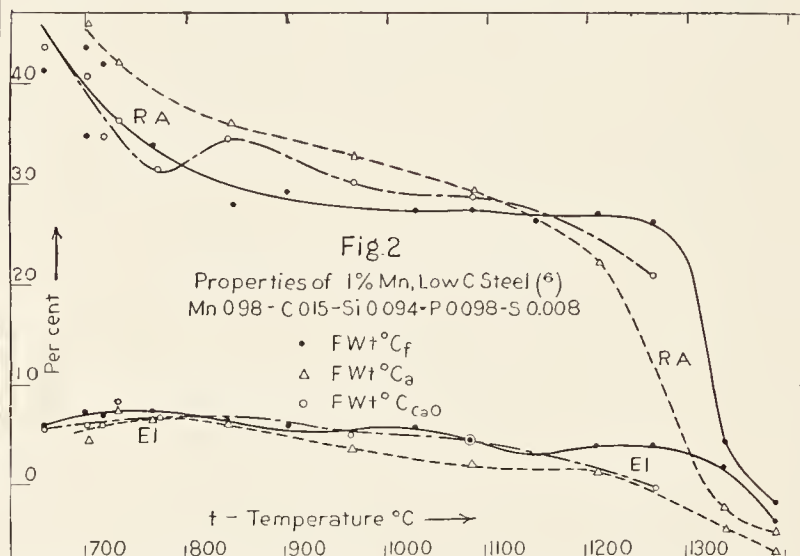
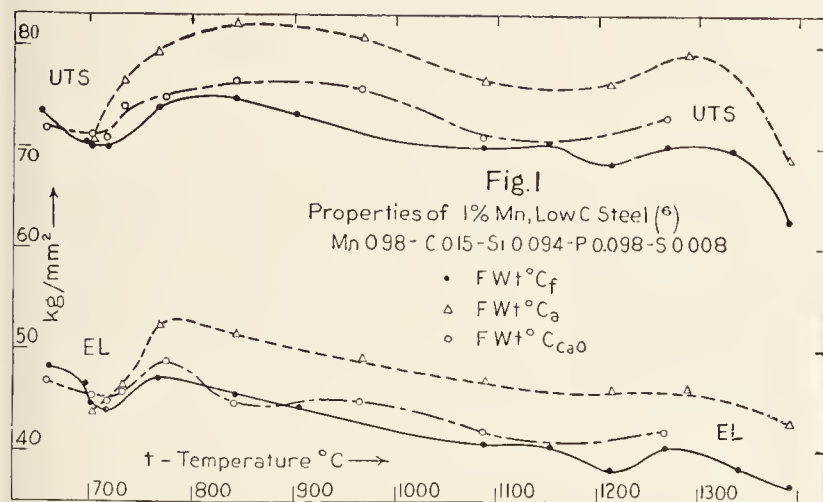


TABLE 7.—TENSILE PROPERTIES OF Fe\*-SI-ALLOYS (38); cf. (31)

% Si	Trt	As forged		A <sub>v</sub> 970° C 30°/h	
		UTS	YP	UTS	YP
0.001		31.5	25.2		
.001		32.8	31.2	25.4	11.5
.001		28.7	26.8		
.010		31.8	29.5	24.6	11.3
.048		32.9	30.1	24.6	14.2
.068		30.9	25.8	24.6	14.3
.091		30.7	25.0	24.9	10.1
.148		31.7	27.1	24.7	11.2
.205		35.0	29.9	27.3	17.6
.230		33.4	29.0		
.242				26.9	12.8
.309				28.4	15.3
.400				29.6	18.3
.472				30.1	12.1
.563	35.9	28.7			
.673	40.8			31.8	18.7
.698				30.2	16.2
.822	39.2	31.8		31.8	18.4
1.71	53.7	47.9		38.1	25.2
1.741				38.8	32.1
2.73				47.7	34.8
3.40	60.6	52.5		54.5	40.2
3.55	69.8	58.6			
4.39	73.9	66.2		59.7†	59.7†
4.44				64.5	51.2
4.92	35.3	35.3			
6.57	3.6	3.6		9.1	9.1

\* Pure electrolytic Fe, melted in vacuo, % C = ca. 0.01. Test pieces ca.

2 5 in. × 0.5 in. diam.

† AN<sub>2</sub> 1030°.TABLE 9.—TENSILE PROPERTIES AND HARDNESS OF ROLLED AND  
FORGED SI-STEELS  
v. also Tables 10-12

Thousandths of % Si-C-Mn-P-S	Treatment, v. p. 392	Tensile tests				Hardness T = TSH B = BHN	Lit *
		10 × UTS	10 × EL	10 × EL	10 × RA		
24-44-36-14-30	R, N 1000° C <sub>a</sub> ...	356	183	430	670		(4, 5)
	R, A 950°†.....	356	313	470	715		
	F.....	386	317	402	683		
180-140-140-50-80 200-140-140-51-80	F.....	520	346	301	545		(15)
	F, A (180)¶.....	394	239	376	607	20 T	
409-208-717-117-61	F.....	602	452			153 B	(12)
	F, W 850° Q <sub>w</sub> ....	838	509			223 B	
433-878-730-57-13	F.....	1152	625			302 B	(12)
	F, W 850° Q <sub>w</sub> ....	1219	976			555 B	
700-180-210 730-180-210	F.....	536	394	295	545		(15)
	F, A (180)¶.....	465	299	340	527	20 T	
870-180-210	F, A (180)¶.....	449	299	255	426		(15)
932-209-Tr.-24-20	F.....	586	377			146 B	(12)
	F, W 850° Q <sub>w</sub> ....	739	416			262 B	
	F, W 950°/4 h....	473	334				
1020-38-79-19-38	R, N 1000° C <sub>a</sub> ...	482	334	355	668		(4, 5)
	R, A 950°†.....	429	317	403	763		
	F.....	485	427	368	674		
1156-835-570-21-17	F.....	1040	625			293 B	(12)
	F, W 850° Q <sub>w</sub> ....	1414	1414			555 B	
1600-190-280† 1520-190-280†	F.....	591	441	311	506		(15)
	F, A (180)¶.....	520	394	351	545	24 T	
1600-117-275-32-12†	F.....	566	452			159 B	(12)
	F, W 850° Q <sub>w</sub> ....	731	640			196 B	
	F, W 950°/4 h....	452	303				
	F, W 950°/8 d....	534	433				
1940-80-110-20-20†	F, N ca. 1000°  .....	500	321	360	624	§	(1)
2090-968-407-32-22	F.....	1054	769			277 B	(12)
	F, W 850° Q <sub>w</sub> ....	1328	1328			578 B	
2110-200-250-40-60† 2130-200-250-40-60†	F.....	622	488	185	280		(15)
	F, A (180)¶.....	536	402	365	600	24 T	

TABLE 9.—TENSILE PROPERTIES AND HARDNESS OF ROLLED AND FORGED SI-STEELS.—(Continued)

Thousandths of % Si-C-Mn-P-S	Treatment, v. p. 392	Tensile tests				Hardness T = TSH B = BHN	Lit.*
		10 × UTS	10 × EL	10 × EL	10 × RA		
2125-(C-Mn, etc. 176)	R, N 1000° C <sub>a</sub> ...	514	337	245	288		(4, 5)
	R, A 950°†.....	473	312	398	659		
	F.....	558	440	280	454		
2690-200-250	F.....	670	504	176	244		(15)
2670-200-250	F, A (180)¶ **.....	504	378	61	66	26 T	
2903-38-61-18-41	R, N 1000° C <sub>a</sub> ...	493	432	42	42		(4, 5)
	R, A 950°†.....	534	345	355	600		
	F.....	586	462	155	146		
3390-210-290‡	F.....	748	552	111	142		(15)
3360-210-290‡	F, A (45)¶.....	614	473	89	93	30 T	
4026-(C, Mn, etc. 242)	R, N 1000° C <sub>a</sub> ...	575		Nil	Nil		(4, 5)
	R, A 950°†.....	687		22	28		
	F.....	659		Nil	Nil		
4180-250-360‡	F.....	772	709	0	2		(15)
4230-250-360‡.....	F, A (15)¶.....	599		6.4	9.8	33 T	
4900-260-290-40-60	F.....	756		3	7		(15)
4800-260-290-40-60	F, A (0)¶.....	394	394	4		36 T	
4885-40-72-21-27	R, N 1000° C <sub>a</sub> ...	572		Nil	Nil		(4, 5)
	R, A 950°†.....	654		Nil	Nil		
	F.....	657		Nil	Nil		
5120-277-380-34-9	F.....	618	526			248 B	(12)
	F, W 850° Q <sub>w</sub> .....	627	528			311 B	
	F, A.....	394	394	5	Nil		
5530-260-290	R, N 1000° C <sub>a</sub> ...	254		Nil	Nil		(4, 5)
	R, A 950°†.....	419		Nil	Nil		
	F.....	315		Nil	Nil		
5998-(C, Mn, etc. 249)	R, N 1000° C <sub>a</sub> ...	326		Nil	Nil		(4, 5)
	R, A 950°†.....	332		Nil	Nil		
	F.....	377		Nil	Nil		
7470-(-)-210-19-11	R, N 1000° C <sub>a</sub> ...	326		Nil	Nil		(4, 5)
	R, A 950°†.....	332		Nil	Nil		
	F.....	377		Nil	Nil		

\* Dimensions of test pieces: (1) 2 in. × 0.564 in. diam.; (4, 5) 2 in. × 0.580 in. diam.; (12) not stated; (13, 15) 2 in. × 0.798 in. diam.; v. also (32, 34, 35).

† Annealed for 40 h and cooled over 170 h.

‡ Steels of commercial importance.

§  $d_4^{20} = 7.733$ .

|| Bar 5 in. long ×  $\frac{3}{4}$  in. diam. bent 180°, radius =  $\frac{5}{16}$  in.

¶ (x) = bars  $\frac{1}{2}$  in. ×  $\frac{1}{4}$  in. cross section bent cold through x°, radius =  $\frac{3}{8}$  in.

\*\* Broke at end in bend test.

TABLE 10.—EFFECT OF LIQUID AIR TEMPERATURE ON FORGED SI-STEEL (13)

Tensile tests* (bars 2.00 in. × 0.18 in. diam.)						
% composition			$t^\circ\text{C}$			
			ca. 20		-182	
Si	C	Mn	UTS	EL	UTS	EL
2.28	0.67	0.50	97.6	15	97.6	0
2.67	0.20	0.25	67.7	17	92.9	0
2.77	0.34		81.9	17	92.9	0
3.03	0.07	0.064	61.4	22	67.7	0
3.89	0.11	0.02	69.3	2.5	39.4	0

\* Treatment: W 1102° C<sub>a</sub> W<sub>2</sub> 777° C<sub>f</sub>.

Brinell hardness number

No. I: Si, 2.28; C, 0.67; Mn, 0.5.

No. II: Si, 3.05; C, 0.11; Mn, 0.08.

No.	I		II	
	At ca. 20°C	At -182°C	At ca. 20°C	At -182°C
p, atm.				
10	305	374	187	328
20	299	396	197	305
40	307	401	206	343

TABLE 11.—COMPRESSION TESTS ON FORGED SI-STEELS (15); v. also (1)

% composition	Si, 0.79; Mn, 0.21; C, 0.18		Si, 2.67; Mn, 0.25; C, 0.20	
	l, in.*	d, in.†	l, in.*	d, in.†
CS				
0	1.0	0.798	1.009	0.798
15.8	0.996	0.799	1.009	0.798
31.5	0.992	0.800	1.008	0.800
47.3	0.947	0.822	0.992	0.808
63.0	0.853	0.890		
78.8	0.814	0.894	0.901	0.850
94.5	0.731	0.950		
110.3	0.658	1.002		
126.0	0.598	1.056		
141.8	0.547	1.115		
157.5	0.503	1.153	0.622	1.035
% composition	Si, 3.46; Mn, 0.29; C, 0.21		Si, 4.49; Mn, 0.36; C, 0.25	
	l, in.*	d, in.†	l, in.*	d, in.†
CS				
0	1.009	0.799	1.008	0.799
15.8	1.009	0.799	1.008	0.799
31.5	1.009	0.799	1.008	0.799
47.3	1.005	0.800	1.005	0.800
63.0			0.990	0.806
157.5	0.646	1.012	0.683	1.003

\* l = length. † d = diameter.

TABLE 12.—PROPERTIES OF CAST SI-STEELS (25)

Treatments:  $\alpha$  = G;  $\beta$  = G, A 1100°/10 h;  $\gamma$  =  $\beta$ , C<sub>s</sub> 900-1000° Q<sub>w</sub>;  $\delta$  = G, A 900°/1 h Q<sub>w</sub>.

No. and Trt		10 × UTS	10 × YP	10 × EL*	10 × RA	BHN†
1	$\alpha$ .....	443	320	300	575	130
	$\beta$ .....	392	269	275	675	118
	$\gamma$ .....	524	345	110	570	160
	$\delta$ .....	573	365	175	652	162
2	$\alpha$ .....	430	335	295	670	131
	$\beta$ .....	398	287	273	695	122
	$\gamma$ .....	554	354	106	540	200
	$\delta$ .....	625	450	156	576	205
3	$\alpha$ .....	457	346	283	580	144
	$\beta$ .....	432	318	260	687	126
	$\gamma$ .....	616	384	100	470	203
	$\delta$ .....	679	450	156	576	205
4	$\alpha$ .....	485	378	282	550	150
	$\beta$ .....	443	318	215	645	136
	$\gamma$ .....	660	400	97	331	216
	$\delta$ .....	699	450	148	550	210
5	$\alpha$ .....	551	420	277	450	168
	$\beta$ .....	513	324	190	560	152
	$\gamma$ .....	756	406	75	162	258
	$\delta$ .....	724	452	132	440	230
6‡	$\alpha$ .....	562	446	262	400	180
	$\beta$ .....	524	336	185	500	174
	$\gamma$ .....	814	524	22	39	269
	$\delta$ .....	776	455	120	335	250
7‡	$\alpha$ .....	587	469	232	395	182
	$\beta$ .....	545	335	182	490	176
	$\gamma$ .....	820	540	22	32	278
	$\delta$ .....	820	457	112	320	258



TABLE 12.—PROPERTIES OF CAST SI-STEELS (25).—(Continued)

No.	Thousandths of %				
	Si	C	Mn	P	S
1	240	120	410	33	64
2	370	100	300	41	49
3	670	110	230	44	44
4	950	110	360	40	43
5	1250	150	500	43	42
6†	1730	150	560	45	40
7‡	2350	120	290	40	58

No.	1	2	3	4	5	6	7
$d_4^{20}\S$	7.861	7.853	7.835	7.810	7.774	7.733	7.702

\* Test pieces 20 cm × 2 cm diam.

† 10 mm ball, 2000 kg load.

‡ Steels of commercial importance.

§ As cast (G).

TABLE 13.—PROPERTIES OF FORGED SI-MN-STEELS (11)

Composition, thousandths of %						Trt	BHN*	10 × UTS	10 × EL	10 × El†	10 × RA	IS‡
C	Mn	Si	P	S								
104	1 728	457	32	8	A§.....	101	476	274	145	305	32	
					N 900°.....	107	498	287	175	582	36	
					850° Qw.....	234	655	444	35	396	16	
210	2 072	1 352	19	8	A§.....	126	583	448	130	342	4	
					N 900°.....	153	602	465	140	572	6	
					850° Qw.....	269	1 155	1 155	0	0	0	
224	14 400	911	24	Tr.	A§.....	202	747	227	120	172	30	
					N 900°.....	212	791	233	100	147	27	
					850° Qw.....	196	706	205	150	186	30	
237	2 150	781	32	10	A§.....	107	559	405	147	305	18	
					N 900°.....	107	558	407	155	572	28	
					850° Qw.....	248	1 070	1 070	10	50	4	
240	14 760	1 880	29	Tr.	A§.....	269	1 032	695	0	0	0	
					N 900°.....	248	945	498	50	60	7	
					850° Qw.....	300	1 078	925	0	0	1	
490	11 940	2 310	32	Tr.	A§.....	196	698	443	190	146	19	
					N 900°.....	202	799	492	100	125	15	
520	11 840	432	17	Tr.	A§.....	153	704	405	200	248	27	
					N 900°.....	196	725	482	190	223	25	
565	450	960	37	Tr.	A§.....	244	725	528	80	60	6	
					N 900°.....	248	765	503	120	145	8	
572	12 007	1 210	28	15	A§.....	153	717	421	190	175	22	
					N 900°.....	202	758	465	150	146	20	
620	525	1 840	25	12	A§.....	269	805	539	60	53	2	
					N 900°.....	293	832	544	100	87	6	

\* 10 mm ball, 3000 kg load.

† Tensile specimens, 10 cm × 1.38 cm diam.

‡ Guillery machine, Fremont test piece 8 × 10 × 10 mm.

§ Forged and annealed at 950° and 1200°.

|| Fremont machine, test pieces 6 mm × 8 mm cross section.

TABLE 14.—EFFECT OF MN CONTENT ON TENSILE STRENGTH AND ELONGATION OF MALLEABLE CAST IRON (24)

% composition (before annealing)					UTS*	El*	Annealing time, hr†
Mn	C	Si	P	S			
0.13	3.06	0.45	0.071	0.041	41.3	3.5	95
					36.1	5.0	130
					32.5	13.0	260
0.26	2.60	0.41	0.078	0.042	45.1	4.5	95
					36.9	6.0	130
					33.6	14.5	260
0.38	3.18	0.32	0.089	0.042	44.6	3.0	95
					37.2	4.8	130
					33.2	14.0	260
0.66	2.58	0.44	0.075	0.044	44.8	3.0	95
					40.8	6.5	130
					34.7	15.5	260
0.78	3.11	0.44	0.078	0.054	46.5	2.5	95
					40.5	5.5	130
					34.5	13.5	260
0.80	2.76	0.47	0.068	0.044	46.9	2.7	95
					41.6	6.5	130
					34.7	15.0	260
0.94	2.76	0.39	0.068	0.050	48.4	3.0	95
					42.4	6.0	130
					35.6	13.5	260
1.05	2.58	0.51	0.056	0.054	50.9	2.3	95
					45.1	6.0	130
					38.0	14.5	260
1.12	2.90	0.41	0.087	0.038	50.4	2.0	95
					45.7	5.0	130
					38.4	15.5	260
1.32	2.82	0.33	0.072	0.038	48.5	1.5	95
					46.6	3.0	130
					40.7	16.0	260
1.52	2.99	0.45	0.076	0.044	53.1	2.0	95
					50.3	3.0	130
					43.2	14.3	260
1.74	3.30	0.36	0.097	0.040	52.1	1.5	95
					48.1	2.0	130
					43.2	11.0	260

\* Test pieces 100 mm × 12 mm diam.

† Annealed with forge, scale at 980°C.

TABLE 15.—EFFECT OF SI CONTENT ON GENERAL MECHANICAL PROPERTIES OF MALLEABLE CAST IRON (23)

Composition, hundredths of %					10 <sup>3</sup> d <sub>4</sub> <sup>20</sup> before annealing	Annealing time, hr*	10 <sup>3</sup> d <sub>4</sub> <sup>20</sup> after annealing	10 × UTS	10 × El†	10 × RA	10 × IS‡	BHN§
Si	C	Mn	P	S								
17	325	11	6.5	5.2	Porous		95	7786	398	40	24	107
							130	378	100	240	40	90
							175	7761	362	108	260	80
							225		350	184	370	92
							260	7770	328	191	415	84
23	332	12	6.1	5.4	7745		95	7785	402	39	24	120
							130		377	94	225	99
							175	7767	364	99	245	36
							225		348	161	350	75
							260	7766	331	180	380	98
30	309	12	6.0	5.0	7746		95	7699	444	40	25	123
							130		372	94	220	101
							175	7683	364	98	240	36
							225		350	162	345	72
							260	7676	336	174	355	79

TABLE 15.—EFFECT OF SI CONTENT ON GENERAL MECHANICAL PROPERTIES OF MALLEABLE CAST IRON (23).—(Continued)

Composition, hundredths of %					10 <sup>3</sup> d <sub>4</sub> <sup>20</sup> before anneal- ing	Anneal- ing time, hr*	10 <sup>3</sup> d <sub>4</sub> <sup>20</sup> after anneal- ing	10 × UTS	10 × El†	10 × RA	10 × IS‡	BHN§
Si	C	Mn	P	S								
38	306	12	5.7	4.9	7742	95	7633	425	31		24	125
						130		372	80	210		106
						175	7614	366	88	225	36	102
						225		353	140	300	72	94
						260	7594	332	161	340	84	91
44	316	12	6.2	5.8	7730	95	7625	436	31		26	127
						130		388	71	185		107
						175	7607	373	84	190	35	104
						225		351	140	260	69	99
						260	7607	342	161	315	72	92
50	297	12	6.6	6.7	7727	95	7632	443	31		22	128
						130		394	72	190		111
						175	7606	377	79	190	33	104
						225		358	139	265	65	100
						260	7602	343	157	310	69	94
55	312	12	6.2	6.8	7709	95	7601	413	28		22	131
						130		377	58	130		113
						175	7566	372	66	145	33	104
						225		353	126	210	58	101
						260	7546	342	148	250	64	96
58	311	13	6.1	5.9	7716	95	7484	425	29		21	129
						130		385	58	130		112
						175	7502	369	68	150	33	129
						225		355	123	240	55	102
						260	7460	344	149	270	58	96
67	327	12	6.8	5.6	7705	95	7440	432	25		22	133
						130		373	47	115		113
						175	7384	366	57	125	32	133
						225		344	123	220	46	97
						260	7357	339	138	240	53	93
71	316	13	5.7	6.4	7701	95	7473	407	22		19	136
						130		378	47	130		117
						175	7497	377	62	135	33	111
						225		351	118	230	47	100
						260	7435	339	134	245	57	99
75	325	14	5.6	5.7	7700	95	7441	424	25		22	133
						130		377	45	125		117
						175	7463	373	58	135	33	112
						225		355	110	230	47	101
						260	7398	342	128	235	55	101
81	317	13	6.8	5.4	7639	95	7343	432	20		19	137
						130		364	39			110
						175	7268	366	57	135	33	108
						225		353	108	190	46	99
						260	7299	339	123	213	51	96
81	324	13	5.8	6.0	7686	95	7364	416	18		22	139
						130		372	40	110		
						175	7386	369	52	130		
						225		353	111	210		100
						260	7328	339	126	215		100
83	332	14	5.3	6.7	7687	95	7384	409	22		21	130
						130		361	39	105		111
						175	7356	361	56	125	32	112
						225		350	108	190	47	101
						260	7328	337	127	220	43	98
94	334	14	5.6	5.6	7682	95	7353	419	22		19	138
						130		374	39	100		113
						175	7339	376	51	105	33	116
						225		355	110	200	47	103
						260	7299	344	123	220	71	99
105	324	14	6.0	5.7	7675	95	7291	429	22		19	133
						130		373	36	80		114
						175	7267	373	50	95	35	116
						225		348	100	165	47	104
						260	7257	336	108	170	50	101
108	319	14	6.6	5.2	7664	95	7248	425	25		21	132
						130		356	33	50		111
						175	7190	350	45	90	33	107
						225		344	96		43	103
						260		317	98	130	46	98

\* Annealed with forge, scale temperature = 980°C.

† Test pieces 100 mm × 12 mm diam.

‡ Small Charpy machine (25 kg-m max. energy), specimens 80 × 10 × 10 mm; impact length 60 mm notch, 2 mm deep × 3 mm wide.

§ 10 mm ball, 1000 kg load.

TABLE 16.—EFFECT OF MN ON PROPERTIES OF CAST IRON

Composition, hundredths of %							UTS*	BMR*	BHN†	ScH	Lit.
Mn	C			Si	P	S					
	Graph- ite	Com- bined	Total								
Graphite, <1.4 %											
35	109	213	322	82			24.4	49.2		58	(7)
200	107	201	308	103			25.8	46.8		65.5	(7)
Graphite, 1.4–1.8 %											
1.6	173	106	279	224	2.7	1.6	15.6	28.4		45	(7)
9.3	156	116	272	157	3.5	0.3	26.0	45.8	183		(37)
16	169	78	247	150	2.2	0.6	25.8	44.6	178		(37)
Graphite, 1.8–2.2 %											
1.4	215	113	328	100	9.0		20.0	34.7		47	(7)
4	210	92	302	162	9.3	1.5	15.9	33.7		43	(7)
23	183	138	321	137	6.2	1.0	25.7	43.2	188		(37)
56	194	69	263	155	2.9	0.5	33.1	53.4	215		(37)
71	215	65	280	153	3.1	0.3	32.8	58.0	213		(37)
79	195	79	274	171	4.1	0.6	32.5	58.2	214		(37)
93	212	78	290	157	3.0	0.3	32.0	60.1	225		(37)
96	215	64	279	154	2.9	0.7	33.1	59.6	221		(37)
171	210	88	298	149	6.2	1.0	29.3	47.3	240		(37)
Graphite, 2.2–2.6 %											
5	225	105	330	100			20.9	45.4		50	(7)
17	225	98	323	155	3.8	1.0	21.7	38.3	175		(37)
31	238	74	312	176	6.1	1.0	32.0	50.6	176		(37)
49	259	66	325	157	3.4	1.4	26.8	48.5	175		(37)
55	243	71	314	130	6.3	0.8	32.5	53.6	180		(37)
65	240	58	298	157	7.5	0.9	35.0	60.2	200		(37)
78	252	62	314	148	3.6	1.0	34.2	59.4	203		(37)
80	236	65	301	145	6.4	1.3	34.8	60.2	202		(37)
84.6	233	82	315	102			26.2	43.8		51.5	(7)
98	230	77	307	143	6.1	0.8	34.5	61.0	209		(37)
106	258	80	338	160	3.3	0.6	26.8	48.0	187		(37)
120	228	80	308	139	6.4	1.4	35.6	62.4	215		(37)
134	225	72	297	155	2.6	0.5	32.0	57.1	217		(37)
141	233	78	311	145	5.7	1.1	36.2	56.6	222		(37)
155	222	70	292	159	2.9	0.4	26.6	52.5	227		(37)
193	259	81	340	160	3.0	0.9	22.8	45.1	197		(37)
196	234	69	303	242			24.4	40.5		43	(7)
222	242	78	320	169			28.7	40.0		42.5	(7)
Graphite, 2.6–3.0 %											
37	263	61	324	150	3.8	0.5	23.3	46.2	173		(37)
54	289	30	319	152	2.7		23.5	34.0		31	(7)
61.1	283	22	305	225			19.1	29.5		31	(7)
63	276	54	330	166	3.0	1.2	26.2	47.3	173		(37)
90	270	56	326	162	3.3	1.0	27.7	47.7	184		(7)
102.3	264	47	311	229			24.4	34.8		38	(7)
103	261	43	304	150			23.8	38.4		40	(7)
124	260	67	327	157	3.8	1.2	27.6	47.5	190		(37)
146	271	73	344	155	3.4	1.0	27.3	48.7	188		(37)
173	261	83	344	159	3.8	1.1	28.1	46.9	191		(37)
Graphite, >3.0 %											
32	302	84	386	156	4.1	1.1	12.8	26.8	127		(37)
52	312	91	403	134	3.0	1.0	13.5	28.2	132		(37)
83	310	77	387	165	3.3	1.4	12.4	26.9	126		(37)
100	310	55	365	182	3.0	0.9	13.1	27.3	125		(37)
136	344	59	403	170	2.9	0.9	12.4	26.0	128		(37)
148	312	94	406	177	3.8	1.2	13.2	28.0	132		(37)
172	329	63	392	185	3.6	0.8	13.1	30.4	137		(37)
188	338	36	374	188	3.6	1.4	12.8	29.5	140		(37)
209	335	51	386	179	2.5	1.4	14.8	30.1	146		(37)
246	328	57	385	185	3.0	1.0	15.0	32.8	158		(37)



TABLE 17.—EFFECT OF MN CONTENT ON HARDNESS OF CAST IRON (8)

White cast iron			
% composition			ScH
Mn	Si	C	
0.03	0.040	3.15	58
1.48		3.28	60
2.82		3.19	65
4.40		3.14	70
5.40	0.083	3.45	73
6.30		3.43	80
7.20	0.081	3.39	59
9.12		3.45	58
10.67	0.072	3.46	54
12.35		3.50	52
13.50		3.49	58
16.00		3.80	67
16.20	0.100	3.45	64
18.65		3.91	60
23.30	0.120	3.85	70
30.50	0.173	3.95	70
34.10	0.156	3.85	71
38.55	0.155	3.93	72

Gray cast iron					
% composition					ScH
Mn	C			Si	
	Total	Graphite	Combined		
0.55	3.66	2.87	0.79	2.45	20
1.00	3.70	3.39	0.31	2.46	37
1.61	3.63	3.16	0.47	2.35	40
2.23	3.60	3.25	0.35	2.35	38
2.65	3.60	3.33	0.27	2.39	33
3.45	3.70	3.12	0.58	2.48	42
4.19	3.80	2.94	0.86	2.44	53
5.15	3.12	2.69	0.43	2.40	55
5.83	3.40	2.65	0.75	2.34	56
6.62	3.24	2.60	0.64	2.40	58
8.35	3.85	2.15	1.70	2.38	63
9.89	3.83	2.10	1.73	2.45	66
10.30	3.95	1.98	1.97	2.41	67
11.15	4.00	1.85	2.15	2.48	65
17.57	4.25	1.14	3.11	2.54	87

TABLE 18.—EFFECT OF SI CONTENT ON CAST IRON

C, 1.8 to 2.2% (33)

Composition, hundredths of %						10 <sup>3</sup> d <sub>4</sub> <sup>20</sup>		E/10	TSH	UTS	UCS
Si	C		Mn	P	S	Cylinders	Turnings				
	Total	Graphite									
19	198	38	14	32	5	7560	7719	1814	72	15.9	118.6
45	200	10	21	33	5	7510	7670	2017	52	19.4	144.0
96	209	24	26	33	4	7641	7630	2192	42	20.0	144.0
196	218	162	60	28	3	7518	7350	1657	22	24.7	96.6
251	187	119	75	26	5	7422	7388	1791	22	23.0	121.6
296	223	143	70	34	4	7258	7279	1487	22	19.2	90.6
392	201	181	84	33	3	7183	7218	1100	27	17.8	75.1
474	203	166	95	30	5	7167	7170	1316	32	16.1	72.8
733	186	148	136	29	3	7128	7138	1036	42	8.3	78.1
980	181	112	195	21	4	6978	6924	980	57	7.6	53.7

Test bars 16 in. × 1½ in. diam.; cast upright, cooled in molds, tested with skin on.

TABLE 18.—EFFECT OF SI CONTENT ON CAST IRON.—(Continued)

C, 2.8 to 3.2% (7)

Composition, hundredths of %						<i>ScH</i>	<i>UTS</i> *	<i>BMR</i> †
Si	C		Mn	P	S			
	Total	Graphite						
40	322	3		1.8	1.1	57	20.5	41.8
50	312	25				56.5	21.6	41.3
80	304	177			1.3	58	15.9	35.9
100	328	215	1.4	9		47	20.0	34.7
111	280	161				49	14.2	31.2
131	305	195			1.1	47	14.2	33.4
162	302	210	4	9.3	1.5	43	15.9	33.7
203	288	180	2			40.5	22.5	32.6
224	279	173	1.6	2.7	1.6	45	15.6	28.4

\*6 in. × ¾ in. diam.

†15 in. × 1 in. sq., 12 in. between supports.

C, 2.9 to 3.25%; Mn, &lt; 0.2%; P, &lt; 0.05%; S, &lt; 0.05% (20)

Hundredths of %			<i>UTS</i>	Hundredths of %			<i>UTS</i>
Si	C			Si	C		
	Total	Graph- ite			Total	Graph- ite	
53	290	Tr.	35.9	196	323	268	23.5
63	290	Tr.	22.8	197	297	147	19.5
66	290	Tr.	21.1	205	312	250	23.6
88	290	Tr.	27.4	207	325	275	13.4
99	290	Tr.	28.5	219	325	275	24.6
110	300	Tr.	25.2	231	310	255	13.2
143	298	28	17.6	236	329	280	15.4
151	300	Tr.	18.3	241	313	240	22.7
168	295	65	18.0	250	305	230	20.6
171	300	Tr.	14.8	250	325	285	14.3
172	307	247	20.0	267	290	250	16.7
173	300	10	18.9	282	306	255	12.9
180	302	11	17.3	294	307	255	12.9
180	315	260	16.9	305	307	260	13.7
195	298	120	30.9				

C, 2.56% to 4.05%\* (36)

Hundredths of %			<i>BHN</i> †	<i>UTS</i> ‡	<i>BMR</i> §
Si	C				
	Total	Graphite			
54	405	229	166	12.8	29.9
80	340	185	206	20.2	40.6
85	319	177	211	21.3	46.5
95	395	263	116	7.2	19.8
118	290	125	244	29.9	53.4
122	322	172	216	23.5	49.0
130	336	228	187	16.2	35.8
137¶	399	260	114	7.7	18.0
155	286	146	236	24.7	45.8
168	342	196	201	18.6	35.1
178	323	199	202	20.3	43.0
183	397	259	111	8.2	18.4
217	340	214	183	15.1	34.0
225	256	145	246	23.5	53.4
225**	320	281	124	14.2	28.4
241	290	228	161	19.5	36.7
282††	263	159	235	20.5	42.5
323‡‡	263	236	130	18.0	35.3

\* Mn, P, S content low except where noted.

† 10 mm ball, 3000 kg load.

‡ 10 cm × 2 cm diam.

§ 60 cm × 3 cm diam.

|| Mn. 17; P. 2; S. 1.6.

¶ Mn, 12; P, 2.7; S, 1.1.

\*\* Mn, 12; P, 4.5; S, 1.

†† Mn, 12; P, 6.3; S, 0.7.

‡‡ Mn, 11; P, 7; S, 0.7 (hundredths of %).

TABLE 19.—EFFECT OF CASTING TEMPERATURE AND ANNEALING ON CAST IRONS OF DIFFERENT SI CONTENT (Mn, <0.2%; P, <0.03%; S, <0.04%) (20)

Hundredths of %			$t_g: t_a, ^\circ\text{C}^*$	$UTS$
Si	C			
	Total	Graphite		
129	325	Tr.	1250	19.4
	328	321	1250:1000	21.4
	325	Tr.	1403	21.1
	326	320	1403:1000	31.0
152	326	26	1201	11.8
	326	16	1300	17.0
	326	10	1403	18.6
	327	320	1300:1000	19.4
	331	323	1403:1000	22.1
170	323	223	1180	17.8
	333	325	1180:1000	16.1
	329	219	1250	16.9
	327	321	1250:1000	12.6
	330	180	1403	16.9
	330	324	1403:1000	17.8
200	331	251	1154	13.2
	332	261	1215	14.5
	332	326	1215:1000	15.8
	330	250	1366	14.3
	329	320	1366:1000	10.6
230	330	257	1135	12.0
	327	321	1135:1000	16.7
	329	255	1215	16.2
	335	328	1215:1000	11.0
	330	260	1300	15.6
	334	327	1306:1000	15.1

TABLE 19.—EFFECT OF CASTING TEMPERATURE AND ANNEALING ON CAST IRONS OF DIFFERENT SI CONTENT (Mn, <0.2%; P, <0.03%; S, <0.04%) (20).—(Continued)

Hundredths of %			$t_g:t_a, ^\circ\text{C}^*$	$UTS$	
Si	C				
	Total	Graphite			
250	{	320	240	1210	13.4
		332	324	1201:1000	8.7
		327	245	1243	11.8
		331	325	1243:1000	5.8
		320	240	1290	14.8
		329	324	1290:1000	6.5

\*  $t_g$  = casting temperature,  $t_a$  = annealing temperature.

## LITERATURE

(For a key to the periodicals see end of volume)

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## STEELS CONTAINING AL, AS, B, CE, SB, TA, OR ZR

W. ROSENHAIN AND EDITH OWER

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TABLE 1.—TENSILE PROPERTIES AND HARDNESS OF AL-STEELS

1000 × % composition						Trt, v. p. 392	BHN	UTS	EL	El*	RA	Lit.
Al	C	Mn	Si	P	S							
C, < 0.10%												
507	85	Tr.	Tr.	29	13	{ F..... Q†.....	81 143	37.1 46.2	26.7 29.1	35 22	68.0 64.1	(4)
7180	83	57	117	20	15	{ F..... Q†.....	159 192	46.1 45.3	40.9 45.3	2 0	0 0	(4)
C, 0.10-0.15%												
1083	113	Tr.	70	16	14	{ F..... Q†..... A‡.....	105 159 51	40.8 51.2 39.8	33.6 40.8 31.5	30 15 26	65.2 20.8 60.1	(4)
3050	134	Tr.	105	16	13	{ F..... Q†.....	131 163	41.4 42.2	27.4 28.3	23.5 4	32.9 1.4	(4)
C, 0.15-0.20%												
380	150	180	180	40	100	{ F..... A‡.....		47.2 40.9	36.2 31.5	37.9 40.4	58.2 60.7	(7)
660	180	140	160	30	90	{ F..... A‡.....		45.7 42.5	32.3 28.3	33.4 33.0	49.9 52.1	(7)
720	170	180	100			{ F..... A‡.....		44.1 39.4	34.6 28.3	40.0 47.1	60.7 64.9	(7)
2045	168	Tr.	Tr.	8	22	{ F..... Q†.....	118 143	44.5 48.9	27.9 31.3	28 7.5	66.7 4.3	(4)
5077	168	83	140	24	17	{ F..... Q†..... A‡.....	143 192 131	50.7 47.3 44.3	34.4 33.5 33.5	21 2 2	45.9 0 0	(4)
C, 0.20-0.25%												
150	220	70	90			{ F..... A‡.....		45.7 39.4	33.0 31.5	36.7 41.3	62.9 63.8	(7)
610	200	110	120			{ F..... A‡.....		44.1 40.1	33.9 28.3	38.4 40.5	54.5 62.0	(7)
1600	210	180	180			{ F..... A‡.....		48.8 40.9	31.5 20.5	32.7 36.4	52.1 67.1	(7)
2200	210	180	180	30	90	{ F..... A‡.....		48.8 44.1	33.0 29.9	22.8 34.9	27.8 47.1	(7)
2240	240	320	180			{ F..... A‡.....		51.2 44.9	33.9 29.1	20.7 33.0	24.6 48.6	(7)
5600	220	220	200	30	80	{ F..... A‡.....		59.8 56.7		3.7 6.5	4.0 6.2	(7)
C, 0.20-0.25% (castings)												
							Diam., mm					
450	240	540	120	23	25	GA.....	22.9	55.7	24.7	19.0	17.0	(11)
1800	200	450	200	23	22	GA.....	16.3	54.3	26.8	13.0	17.0	(11)
2750	200	500	230	22	20	GA.....	16.3	51.9	25.2	10.0	0.0	(11)
3600	230	470	200	23	20	GA.....	14.7	51.3	26.8	2.5	0.0	(11)
4600	200	500	180	22	20	GA.....	22.9	50.5	25.2	3.1	0.0	(11)
C, 0.25-0.30%												
1160	260	110	150	40	80	{ F..... A‡.....		51.9 45.7	36.2 33.0	32.1 34.4	51.5 53.0	(7)
230	300	400	100	27	22	GA.....	16.3	60.8	24.9	14.0	13.5	(11)
950	280	500	150	23	20	GA.....	16.3	55.1	25.2	13.0	15.0	(11)
2700	300	1250	220	25	23	GA.....	21.1	63.0	31.5	8.5	0.0	(11)
C, 0.30-0.75%												
							BHN					
45	736	100	140	15	8	F.....	228	83.3	45.7	5	17.3	(4)
1052	669	141	198	8	12	F.....	212	88.8	46.6	9	20.5	(4)
2890	691	152	186	6	18	{ F..... Q†.....	228 269	73.8 95.5	43.6 58.4	4 3	4.5 4.5	(4)
7000	663	140	256	50	25	{ F..... Q†.....	217 255	89.4 102.5	68.4 75.8	0 0	0 0	(4)
C, > 0.75%												
1094	796	208	362	13	14	A‡.....	228	92.5	45.2			(4)
4650	815	122	221	24	24	F.....	277	88.8	46.7	11	15.4	(4)
14900	860	398	232	32	18	{ F..... Q†.....	277 262	101.9 103.4	66.2 56.5	3 0	42 0	(4)

\* Test pieces (6) are 2 in. × 0.7979 in. diam.; dimensions of others not stated.

† 850° Q<sub>w</sub>. ‡ A 900°/4 b

TABLE 2.—COMPRESSION TESTS ON AL-STEELS (7)

Test pieces (as forged) subjected to compressive stress of 157.5 kg/mm<sup>2</sup>.

100 × % composition						l <sub>0</sub> *	d <sub>0</sub> *	-100 $\frac{\Delta l}{l_0}$	100 $\frac{\Delta d}{d_0}$
Al	C	Mn	Si	P	S				
15	22	7	9			0.9970	0.7970	51.00	1.24
66	18	14	16	3	9	1.0025	0.7965	49.08	1.17
116	26	11	15	4	8	0.9985	0.7960	47.22	1.13
160	21	18	18			1.000	0.7972	48.10	1.14
224	24	32	18			1.0011	0.7969	45.40	1.11
560	22	22	20	3	8	0.9992	0.7966	36.57	1.04

\* l<sub>0</sub> = original length, d<sub>0</sub> = original diameter.

TABLE 3.—SPECIFIC GRAVITY OF AL-STEELS

% composition*		d <sub>4</sub> <sup>20</sup>		Lit.
Al	C	Cast	Forged	
0.72	0.17		7.755	(7)
0.61	0.20		7.781	(7)
1.60	0.21		7.6237	(7)
2.24	0.24		7.554	(7)
5.6	0.22		6.6726	(7)
0.45	0.24	7.73	7.77	(11)
1.80	0.20	7.62	7.67	(11)
2.75	0.20	7.44	7.58	(11)
3.60	0.23	7.35	7.48	(11)
4.6	0.20	7.27	7.40	(11)
0.23	0.30	7.78	7.79	(11)
0.95	0.28	7.70	7.72	(11)
2.70	0.30	7.45		(11)

\* For complete analyses, v. Table 1.

TABLE 4.—MECHANICAL PROPERTIES OF AS-STEELS

1000 × % composition							Trt,* v. p. 392	UTS	YP	El	RA	Lit.
As	C	Mn	Si	Cu	P	S						
C, <0.3 %												
123	77	436	58	168	17	54	{ A..... Q.....	35.7 41.2	26.1 27.4	27.2 27.9	55.3 52.2	(8)
277	76	440	54	196	20	60	{ A..... Q.....	37.2 42.5	26.9 29.2	26.9 24.0	55.4 51.6	(8)
405	78	431	57	182	17	57	{ A..... Q.....	38.5 43.8	27.1 31.7†	26.5 23.2	55.8 46.2	(8)
549	77	448	52	192	18	52	{ A..... Q.....	39.5 44.4	27.3 31.9	25.9 23.0	55.1 45.4	(8)
691	75	439	62	200	16	60	{ A..... Q.....	41.3 45.5	30.1 32.2	25.6 22.7	53.0 43.4	(8)
880	76	435	54	207	20	55	{ A..... Q.....	42.0 48.0	31.6 34.9	25.6 21.7	52.4 39.2	(8)
1172	81	433	49	198	23	55	{ A..... Q.....	44.0 48.3	33.8 35.8	25.3 22.8	51.2 42.8	(8)
1425	80	429	49	192	26	51	{ A..... Q.....	46.0 47.9	34.3 34.8	20.8 21.6	42.3 33.3	(8)
1570	40	10	30	‡	30	20	C <sub>a</sub> .....	42.6	27.9†	28.5§	34.1	(1)
1621	83	434	46	188	26	55	{ A..... Q.....	48.8 48.8	36.1 34.7	20.2 18.6	34.1 27.5	(8)
1943	79	434	47	184	21	56	{ A..... Q.....	47.5 50.4	36.7 35.2	8.9 11.9	15.5 9.8	(8)
2240	83	429	52	187	24	55	{ A..... Q.....	42.5 49.4	36.6 34.3	5.15 10.0	9.1 2.8	(8)
2534	86	446	55	192	19	52	{ A..... Q.....	41.0 49.8	36.9 38.6	4.55 9.10	1.1 1.7	(8)
2841	84	440	55	189	21	50	{ A..... Q.....	36.5 44.1	35.5 39.2	1.88 4.14	0.0 1.1	(8)
3130	85	446	53	193	17	57	{ A..... Q.....	35.7 44.4	35.7 44.0	0.0 1.97	0.0 0.0	(8)
3284	85	442	59	186	17	51	{ A..... Q.....	35.1 39.5	35.1 38.8	0.0 1.10	0.0 0.0	(8)
3515	68	352	46	152	13	40	{ A..... Q.....	35.8 38.8	38.8 38.8	0.0 0.0	0.0 0.0	(8)

TABLE 4.—MECHANICAL PROPERTIES OF AS-STEELS.—  
(Continued)

1000 X % composition						Trt,* v. p. 392	UTS	YP	El	RA	Lit.	
As	C	Mn	Si	P	S							
C, 0.30-0.45 %												
93	360	1140	115	89	26	R.....	72.4	22.7	17	43	(10)	
178	360	1020	123	55	40	R.....	57.5		20		(10)	
185	355	1000	122	68	36	R.....	57.5		18.5		(10)	
193	405	1170	147	74	26	R.....	78.7	28.5	13	28	(10)	
197	365	1200	109	64	34	R.....	72.9	21.0	19	47	(10)	
208	360	1010	125	55	40	R.....	58.3		19.5		(10)	
266	400	1110	168	77	34	R.....	80.2	27.5	13	33	(10)	
272	360	1200	103	88	36	R.....	72.4	21.5	17	41	(10)	
274	395	1120	150	87	46	R.....	72.4	24.0	17	32	(10)	
278	425	1210	153	83	36	R.....	77.3	28.5	22	29	(10)	
293	355	940	127	62	36	R.....	60.4		14		(10)	
301	365	1120	94	94	40	R.....	72.4	26.5	16	43	(10)	
328	365	1000	131	77	38	R.....	59.9		15.5		(10)	
334	356	1200	109	97	36	R.....	74.5	22.0	16	36	(10)	
340	400	1160	141	99	40	R.....	78.7	29.0	15	35	(10)	
367	395	1100	141	97	34	R.....	80.0	32.0	15	27	(10)	
618	355	1000	125	72	40	R.....	59.5		16		(10)	
672		930	94	84	44	R.....	62.5		20		(10)	

TABLE 4.—MECHANICAL PROPERTIES OF AS-STEELS.—  
(Continued)

1000 × % composition						Trt,* v. p. 392	UTS	YP	El	RA	Lit.
As	C	Mn	Si	P	S						
C, > 0.45 %											
243	495	1100	177	63	50	R.....	89.3	32.0	12	25	(10)
278	490	1110	156	77	40	R.....	83.6	31.0	10	12	(10)
278	500	1090	156	63	46	R.....	84.4	30.0	12	20	(10)
296	500	1080	195	87	34	R.....	88.6	33.5	11	19	(10)
317	515	1090	141	91	40	R.....	87.2	35.0	11	16	(10)
329	505	1170	125	86	44	R.....	85.8	32.0	13	20	(10)

\* A = A 880°/90 C<sub>a</sub> (in absence of air); Q = 910°/40 Q<sub>w</sub>; C<sub>a</sub> = R (1 in. diam.), W > 1000°, C<sub>a</sub>; R = from head of a rail.

† These values are for elastic limit.

‡ Contains 0.003 % Al.  $d_4^{20} = 7.8690$ .

§ Test pieces from rolled bars, 2 in. × 0.564 in. diam.

## COMPRESSION TEST OF 0.04 % C-STEELS CONTAINING AS (1)

100 × % composition							CS Trt*	% compression				
As	C	Mn	Si	Al	P	S		31.5	63.0	94.5	126.0	157.5
157	4	1	3	3	3	2	N.....	3.0	15.5	31.4	44.6	53.0
							H.....	0.9	12.3	27.0	40.3	49.1

\* N = normalized; H = W > 1000° Q<sub>w</sub> (test pieces 28.7 mm × 14.32 mm diam.).

TABLE 5.—MECHANICAL PROPERTIES OF B- AND NI-B-STEELS

Boron steels difficult to roll at ordinary rolling temperature (1100°C). Ingots for (2): specimens rolled at 960°, but some plates showed cracks.

% composition								Trt, v. p. 392	UTS	YP	PL	El <sub>a</sub> *	RA	BHN	ScH	IS† kg/m	IS'‡ kg-m/cm <sup>2</sup>	Lit.	
B	C	Ni	Al	Mn	Si	P	S												
B-Steels																			
0.215	0.180			0.076	0.232	0.023	0.012	{ N 850° Q <sub>w</sub>	37.4 68.4			20.2 57.0	34.5 7.5	57.5 36.5			3.05 5.95		(5)
0.39	0.16		0.06	0.68	0.24	<0.015	<0.035	{ N 880° 880° Q <sub>o</sub> Tp	49.1 67.5	32.5		10.7 35.8	23.8 3.9	156 217	15 30		0.79		(2)
0.462	0.224			0.292	0.163	0.015	0.015	{ N 850° Q <sub>w</sub>	39.6 147.5			20.2 99.9	27.0 6.5	55.0 30.6			3.05 5.95		(5)
0.57	0.21		0.02	0.80	1.50	<0.015	<0.035	{ N 880° 880° Q <sub>o</sub> Tp	59.5 105.4	40.8 103.6		38.0 56.9	11.5 0.5	25.6 9.8	217 555		43	1.03	(2)
0.844	0.207			0.600	0.792	0.013	0.014	{ N 850° Q <sub>w</sub>	50.1 174.9			29.8 129.9	14.0 4.0	26.8 10.6			3.05 5.95		(5)
1.514	0.281			0.600	0.641	0.018	0.005	{ N 850° Q <sub>w</sub>	51.7 126.0			31.5 120.0	5.5 1.0	4.5 0.0			1.94 3.05		(5)
0.06	0.45		0.03	0.69	0.33	<0.015	<0.035	{ N 820° 820° Q <sub>o</sub> Tp§	70.6 60.0	59.6		17.0 0.1	41.7 0.7	187 387	23 52		0.77		(2)
0.155	0.475			0.370	0.283	0.020	0.020	N	50.9			34.5	17.0	27.0			1.94		(5)
0.406	0.595			0.295	0.292	0.023	0.016	N	54.0			39.0	18.0	22.8			3.05		(5)

\* In (2) specimens are 2 in. × 0.3 in. diam. PL by Berry strain gage.

† Machine and type of specimens not stated.

‡ Tests made on Izod machine. Specimens: 0.35–0.45 in. diam., 45° V notch, 0.13 in. deep, bottom radius = 0.01 in.

§ Tp = Tp<sub>0</sub> 175°/3 h, C<sub>0</sub>.



TABLE 7.—MECHANICAL PROPERTIES OF CE- AND NI-CE-STEELS (2)

% composition*					Trt, v. p. 392	UTS	YP	PL	El†	RA	BHN	ScH	IS'§ kg-m/cm²
Ce†	C	Ni	Mn	Si									
Ce-Steels													
0.20	0.39		0.68	0.75	{ N 840° 840° Q <sub>o</sub> Tp	65.8	39.8	26.0	6.3	54	163	17	1.54
						90.1		59.7		0.7	418	32	
0.35	0.40		0.69	0.27	{ N 820° 820° Q <sub>o</sub> Tp	59.5	50.0	19.0	8.5	31.1	185	25	2.75
						132.7		84.3		10.0	248	128	
Ni-Ce-Steels													
0.01	0.45	2.95	0.71	1.30	{ N 820° 820° Q <sub>o</sub> Tp	101.1	94.4		15.6	40.8	269	24	1.54
						218.8	145.1		8.5	37.2	555	52	
0.06	0.41	2.80	0.73	1.70	{ N 840° 840° Q <sub>o</sub> Tp	100.8		42.2	7.5	37.6	285	39	3.73
						209.3	172.0	123.0	7.5	7.2	555	58	
0.10	0.46	2.90	0.98	1.55	{ N 840° 840° Q <sub>o</sub> Tp	123.9	72.6	38.0	9.5	5.4	321	41	1.54
						219.5	165.2	129.3	4.6	7.3		66	
0.31 <sub>T</sub> 0.19 <sub>B</sub>	0.42	2.95	1.15	0.80	{ N 780° 780° Q <sub>o</sub> Tp	89.4	56.2	37.2	21.0	17.8	217	37	2.08
							142.3	104.7	45.7	8.6	10.4	222	
0.55 <sub>T</sub> 0.35 <sub>B</sub>	0.44	3.00	0.91	1.30	{ N 800° 800° Q <sub>o</sub> Tp	111.5	100.3		5.5	17.3	302	36	5.41
							228.2	203.0	58.3	5.5	11.0	600	
1.35 <sub>T</sub> 0.66 <sub>B</sub>	0.39	2.65	0.90	0.25	{ N 780° 780° Q <sub>o</sub> Tp	76.7	52.0	35.2	7.6	16.0	187	34	1.46
							124.8	108.6	64.0	2.5	2.1		
0.03	0.51	2.90	1.04	1.35	{ N 780° 780° Q <sub>o</sub> Tp	108.4		49.2	1.0		396	40	1.01
	( +Cu 0.62)					176.8		98.4	1.0	14.1	530	52	
0.22 <sub>T</sub> 0.07 <sub>B</sub>	0.74	2.25	0.82	1.25	{ N 805° 805° Q <sub>o</sub> Tp	120.2	81.0	70.3	10.5	36.1	359	48	1.01
										(Broke in shoulder)			

\* These steels contain &lt;0.015 % P, &lt;0.035 % S.

† Where two values are given for % Ce, subscripts T and B refer to samples taken from top and bottom of ingot respectively (in amounts over 0.30 %, Ce segregates very badly).

‡ Tensile specimens 2 in. × 0.30 in. diam.

§ Izod machine used. Specimens 0.30 in. to 0.45 in. diam., 45° V notch, 0.13 in. deep, bottom radius = 0.01 in.

|| Tp = Tp<sub>o</sub> 175°/3 h C<sub>a</sub>.

TABLE 6.—HARDNESS OF B-STEELS\* (3)

% B	% Ni	BHN†	% B	% Ni	BHN†	% B	% Ni	BHN†
0.4		108.5	0.78	4.75	242.5	2.1	10.7	435
0.73		175	0.85	4.72	242.5	2.51	10.0	454
1.21		227	1.32	4.80	341.5	3.38	10.4	571.5
1.93		242.5	2.18	5.0	521.5	4.24	10.0	712
2.41		214	2.52	4.7	356	0.69	20.0	385.5
3.26		318	3.15	4.93	521.5	2.17	19.81	400.0
4.32		560	4.41	4.81	521.5	1.04	22.0	208?
2.3	1.3	227	2.39	7.0	418	1.42	25.0	400
4.27	1	571.5	0.71	10.2	355	3.9	25	296
2.76	2.1	250	0.84	10.2	370			
4.32	2	712	1.31	10.25	419			

\* Prepared from Swedish iron containing: C, 0.1; Mn, 0.14; Si, 0.014; P, 0.08; S, 0.012; ferroboron containing B, 19.56; C, 0.17; and pure Ni.

† 10 mm, 3000 kg.

TABLE 9.—SPECIFIC GRAVITY OF FE-SB-ALLOYS (9)

% Sb.	18.80	38.80	44.98	56.88	60.80	64.58	74.31	81.52
d <sub>4</sub> <sup>0</sup> .....	7.800	8.120	8.159	8.298	8.071	8.300	7.912	7.211

TABLE 8.—PROPERTIES OF SB-STEELS (12)

100 × % composition							UTS	YP	El†	RA	d <sub>4</sub> <sup>0</sup>
Sb	C	Cu	Mn	Si	P	S					
2	10	6	37	4	Tr.	7	35.4	20.0	33.5	75.0	8.2
5	11	16	56	4	Tr.	5	34.4	20.5	30.1	75.0	

† Test pieces 56 mm × 5.65 mm.

TABLE 10.—MECHANICAL PROPERTIES OF TA-STEELS (6)

% composition*				Trt, v. p. 392	UTS	EL	El†	RA	BHN
Ta	C	Mn	Si						
0.09	0.12	0.19	0.12	{ N 875° Q <sub>w</sub> 20°	41.5	29.8	33	67.4	107
					65.0	46.9	14.5	71	159
0.15	0.17	0.15	0.19	{ N 875° Q <sub>w</sub> 20°	42.6	30.4	31	68.8	107
					62.1	45.7	15	73	153
0.60	0.18	0.22	0.24	{ N 875° Q <sub>w</sub> 20°	45.3	31.1	28	67.4	112
					65.8	46.6	13	74.9	155
1.05	0.16	0.23	0.16	{ N 875° Q <sub>w</sub> 20°	47.8	31.5	28	62.3	116
					70.0	49.1	10	55.8	169

\* All contain traces of P and S.

† Dimensions of test pieces not stated.

TABLE 11.—PROPERTIES OF ZR- AND NI-ZR-STEELS (2)

% composition *							Trt, v. p. 392	UTS	YP	PL	El <sub>a</sub> †	RA	BHN	ScH	IS'‡ kg-m/cm <sup>2</sup>
Zr	C	Ni	Mn	Si	Al	Ti									
Zr-Steels															
0.25	0.23		0.61	1.30	Tr.	0.05	{ N 900° 900° Q <sub>o</sub> Tp§	55.7 69.7	31.6 43.8	19.7 16.2	28.5 23.5	60.8 55.0	179 187	24 22	5.08
0.20	0.37		0.50	0.73	0.02	0.03	{ N 860° 860° Q <sub>o</sub> Tp§	66.8 69.9	35.5	21.1 16.9	10.0 9.5	22.8 21.3	179 196	27 25	
0.22	0.36		0.77	1.70	Tr.	0.06	{ N 860° 860° Q <sub>o</sub> Tp§	75.0 135.4		30.2 63.2	24.5 5.0	53.0 19.8	206 286	17 35	1.76
0.50	0.33		0.63	1.5	Tr.	0.10	{ N 860° 860° Q <sub>o</sub> Tp§	65.0 95.3	33.7	22.5 24.6	22.5 9.0	51.5 30.1	189 228	27 27	2.49
0.60	0.34		0.69	1.70	Tr.	0.07	{ N 860° 860° Q <sub>o</sub> Tp§	70.8 98.6	43.6 64.6		24.5 12.5	53.7 26.8	207 187	30 31	2.66
0.03	0.45		0.67	0.50	0.02	0.02	{ N 825° 825° Q <sub>o</sub> Tp§	69.6 115.6		29.5 38.0	19.5 5.0	39.8 8.5	185 241	27 27	
0.03	0.42		0.76	1.55	Tr.	0.03	{ N 860° 860° Q <sub>o</sub> Tp§	81.1 104.5	53.8 90.2	33.0 52.7	19.0 1.5	52.3 32.0	212 269	29 31	2.70
0.11	0.47		0.78	0.85	0.15	0.02	{ N 800° 800° Q <sub>o</sub> Tp§	77.8 103.6		21.8 35.1	16.0 0.5	22.7 2.2	207 292	31 28	
0.15	0.42		0.55	0.44	0.13	0.01	{ N 860° 860° Q <sub>o</sub> Tp§	71.0 165.9	37.4 144.8	27.4 88.6	8.0 1.5	20.3 4.5	186 509	25 54	
0.09	0.56		0.75	0.54	0.07	0.02	{ N 810° 810° Q <sub>o</sub> Tp§	70.8 142.5	39.3	35.1	11.0 0.25	18.7 0.0	197 454	27 43	
0.10	0.51		0.80	1.15	0.09	0.04	{ N 840° 840° Q <sub>o</sub> Tp§	81.0 184.1		37.2 56.2	16.0 1.5	38.6 2.0	228 520	29 44	
Ni-Zr-Steels															
0.12	0.39	3.15	0.90	1.05	0.01	0.02	{ N 830° 830° Q <sub>o</sub> Tp§	182.0 188.0		37.9 95.6	4.0 1.0	5.2 4.5	375 512	32 39	
0.13	0.43	2.00	0.87	1.10	0.17	0.11	{ N 820° 820° Q <sub>o</sub> Tp§	98.2 206.3	61.1	42.9 116.6	19.5 7.0	44.9 24.1	255 477	31 37	2.32
0.25	0.51	3.00	0.72	1.20	0.04	0.01	{ N 780° 780° Q <sub>o</sub> Tp§	137.1 204.7		42.2 81.9	4.0 3.0	11.6 4.0	255 440	20 36	

\* All steels contain &lt; 0.015 % P and &lt; 0.035 % S.

† Tensile specimens, 2 in. × 0.3 in. diam.

‡ Izod machine specimens 0.30–0.45 in. diam., 45° V notch, depth = 0.13 in., radius of bottom = 0.01 in.

§ Tp = Tp 175°/3 h C<sub>a</sub>.

## LITERATURE

(For a key to the periodicals see end of volume)

(1) Arnold, 140, 45: 107; 94. (2) Burgess and Woodward, 32, No. 207; 22. (3) Chiyevskii and Mikhailovskii, 74, 14: 16; 17. 431, 1: 547; 15.

(4) Guillet, 74, 2: 312; 05. (5) Guillet, 34, 144: 1049; 07. (6) Guillet 34, 145: 327; 07. (7) Hadfield, 140, 37: 161; 90. (8) Liedgens, 77, 32: 2109; 12. (9) Maey, 7, 38: 292; 01. (10) Mitinsky, 431, 1: 650; 13. 10, 4: 1324. (11) Riley, 140, 36: 161; 90. (12) Schleicher, 77, 42: 781; 22.

## PROPERTIES OF ALUMINIUM AND ITS ALLOYS WITH CU, MG, MN, NI, SI, SN, AND ZN CONTAINING MORE THAN 50% Al (v. also p. 542)

S. L. ARCHBUTT

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The following properties of pure Al are given elsewhere: specific gravity, p. 456; compressibility, vol. III; viscosity, vol. III; surface tension, vol. III.

TABLE 1.—TENSILE PROPERTIES  
Al

% composition*	Treatment	UTS	YP	PL	El	RA	Lit.
Al, 99.97...	Wk, A	5.96			60 <sub>a</sub>	95	(10)
Al, 99.6; Fe, 0.14; Si, 0.19	R, $\frac{1}{8}$ in. thick† R, rod‡	4.41–6.43 4.7–6.3			34–86 <sub>b</sub> 55–87 <sub>b</sub>		(8)
Al, 99.54; Fe, 0.14; Si, 0.25; Na, 0.07	G <sub>s</sub> , 0.56 in. § G <sub>s</sub> , 450° C <sub>s</sub> G <sub>s</sub> , 450° Q <sub>w</sub> G <sub>m</sub> , 1 in. R <sub>h</sub> , $\frac{5}{4}$ in. § R <sub>h</sub> , $\frac{11}{8}$ in. § DA, $\frac{11}{8}$ in. § D <sub>c</sub> , $\frac{11}{8}$ in. § $\frac{1}{4}$ in. thick Same, A 500° $\frac{1}{8}$ in. thick Same, A 500° $\frac{1}{2}$ in. thick Same, A 500°	7.72 7.21 7.95 8.23 10.24 11.34 11.69 13.70 13.16 9.31 14.45 9.29 14.71 9.18	3.9 3.0 3.8 3.6 6.9 10.2 11.0 13.4 12.4 4.25 13.5 4.7 13.2 4.0		24 <sub>a</sub> 19.0 <sub>a</sub> 22.0 <sub>a</sub> 37.0 <sub>a</sub> 35.5 <sub>a</sub> 30.5 <sub>a</sub> 23.0 <sub>a</sub> 19.5 <sub>a</sub> 10.6 <sub>b</sub> 41.0 <sub>b</sub> 6.3 <sub>b</sub> 31.0 <sub>b</sub> 3.7 <sub>b</sub> 36.3 <sub>b</sub>	39.4 27.4 33.8 60.7 79.4 81.2 82.1 73.3	(7)
Al, 99.30...	R <sub>d</sub> sheet R <sub>d</sub> bars D <sub>d</sub> wire	15.5–24.6 19.7–24.6 17.6–38.7			1–7 <sub>a</sub>	20–30 30–40 40–50	(6)
Al, 99.24; Fe, 0.49; Si, 0.15	R, $\frac{1}{4}$ in. diam.	15.90		7.92	16 <sub>a</sub>	65.4	(22)
Al, 99.20...	G <sub>s</sub> , $\frac{1}{4}$ in. Wk <sub>d</sub> , 75 % Same, A	9.5 15.8 9.5	2.8¶ 12.7 3.2	0.7 7.0 1.4	24** 13 40		(11)
Al, 99.07–98.46; Fe, 0.70–0.98; Si, 0.23–0.56	Strip, A†† R <sub>c</sub> , 50 % R <sub>c</sub> , 200–300 % Same, A 400°††	9.0–10.1 14.2 15.0–18.1 10.99		4.6–3.9 11.5–12.0 14.2–17.6 5.0	40–38 <sub>i</sub> 9–11 <sub>i</sub> 2–1.5 <sub>i</sub> 40 <sub>i</sub>		(14)

\* Al content by difference.

† Single crystal, test piece  $1 \times \frac{1}{4}$  in. cross-section.

‡ Single crystal, test piece 0.564 in. diam.

§ Dimensions are for diam. after indicated mechanical treatment, test piece, 0.564 in. diam.

|| Contains 0.12 % Cu.

¶ Stress at  $\Delta l = \frac{1}{2} \% l_0$ .

\*\* Gage length =  $4 \times$  diam.

†† 0.5–10 mm thick from 40 mm slabs.

‡‡ Optimum conditions for completely annealed product (Grard).

Al-Cu\* (7)

Treatment	UTS	YP	El <sub>a</sub> †	RA	UTS	YP	El <sub>a</sub> †	RA
	Cu, 0.86 %				Cu, 1.90 %			
G <sub>s</sub> , to shape.....	8.06	4.1	12.5	12.1	7.20	5.2	5.5	18.4
Same { 450° C <sub>s</sub> .....	8.24	3.9	10.5	11.8	7.32	5.2	6.0	22.7
450° Q <sub>w</sub> .....	8.95	4.4	13.0	21.5	7.89	5.7	7.0	9.1
G <sub>m</sub> , 1 in. diam.....	9.64	4.9	15.5	33.3	12.88	6.1	17.0	26.4
R <sub>h</sub> { $\frac{5}{4}$ in. diam.....	14.72	8.7	30.0	72.9	17.16	10.1	27.5	61.7
$\frac{7}{8}$ in. diam.....	16.49	12.0	28.5	73.3	22.66	20.2	19.0	58.2
DA, $\frac{13}{16}$ in.....	16.90	16.1	19.0	71.7	21.72	20.3	16.5	59.4
D <sub>c</sub> , $\frac{13}{16}$ in.....	20.27	19.2	14.5	63.3	23.62	22.1	13.0	46.5
	Cu, 0.93 % (sheet)				Cu, 1.57 % (sheet)			
R <sub>c</sub> , $\frac{1}{4}$ in. thick.....	18.8	17.3	7.0		21.72	20.5	5.3	
Same, A 500°.....	12.9	5.8	28.7		15.78	7.1	24.7	
R <sub>c</sub> , $\frac{1}{16}$ in. thick.....	20.4	18.1	4.7		25.5	20.0	5.3	
Same, A 500°.....	12.7	6.0	31.7		16.42	7.2	25.3	
R <sub>c</sub> , $\frac{1}{20}$ in. thick.....	19.2	18.4	3.3		23.89	21.7	3.3	
Same, A 500°.....	13.4	5.4	29.2		16.70	6.5	25.7	

Al-Cu\* (7).—(Continued)

Treatment	UTS	YP	El <sub>a</sub> †	RA	UTS	YP	El <sub>a</sub> †	RA
	Cu, 2.77 %				Cu, 3.76 %			
G <sub>s</sub> , to shape.....	8.22	5.8	4.5	11.0	11.80	7.7	5.0	7.3
Same { 450° C <sub>s</sub> .....	8.76	6.8	5.0	7.3	11.84	7.7	4.0	12.0
450° Q <sub>w</sub> .....	8.41	7.2	5.0	8.0	11.10	9.0	4.0	12.2
G <sub>m</sub> , 1 in. diam.....	13.54	7.7	10.5	24.6	15.12	8.5	10.5	21.5
R <sub>h</sub> { $\frac{5}{4}$ in. diam.....	21.87	10.6	26.5	52.2	26.5	14.2	20.0	38.2
$\frac{7}{8}$ in. diam.....	26.1	19.7	16.0	44.6	26.8	18.3	21.0	49.8
DA, $\frac{13}{16}$ in.....	Drew hollow‡				26.6	24.4	8.0	21.8
D <sub>c</sub> , $\frac{13}{16}$ in. §.....	28.0	25.8	9.5	27.6	31.5	29.1	7.5	20.8
	Cu, 2.36 % (sheet)				Cu, 3.74 % (sheet)			
R <sub>c</sub> , $\frac{1}{4}$ in. thick.....	22.24	21.1	4.3		24.58	23.5	4.0	
Same, A 500°.....	15.25	7.9	28.6		16.95	6.8	24.0	
R <sub>c</sub> , $\frac{1}{16}$ in. thick.....	23.37	18.3	5.3		27.7	26.5	4.0	
Same, A 500°.....	18.26	7.6	25.3		17.32	8.0	21.0	
R <sub>c</sub> , $\frac{1}{20}$ in. thick.....	26.54	24.1	4.0		29.25	25.0	4.0	
Same, A 500°.....	18.53	7.1	24.7		18.36	7.7	24.7	
	Cu, 4.97 %				Cu, 6.15 %			
G <sub>s</sub> , to shape.....	10.60	8.2	4.0	5.0	12.16	9.6		3.5
Same { 450° C <sub>s</sub> .....	12.36	8.7	4.0	1.2	11.46	10.2	3.0	5.0
450° Q <sub>w</sub> .....	11.51	9.8	4.0	1.1	12.76	11.0	3.5	1.5
G <sub>m</sub> , 1 in. diam.....	15.15	9.3	6.0	9.7	15.62	8.3	5.0	10.6
R <sub>h</sub> { $\frac{5}{4}$ in. diam.....	23.10	14.0	19.5	36.9	25.78	14.3	18.0	33.8
$\frac{7}{8}$ in. diam.....	23.86	16.4	19.5	36.4	27.20	20.6	15.5	33.6
D <sub>c</sub> , $\frac{17}{16}$ in.....	27.9	25.0	6.0	20.8				
	Cu, 4.74 % (sheet)				Cu, 5.34 % (sheet)			
R <sub>c</sub> , $\frac{1}{4}$ in. thick.....	25.22	23.3	2.0		21.36	19.7		
R <sub>c</sub> , $\frac{1}{16}$ in. thick.....	23.89	22.5	4.7		20.90	19.4		
Same, A 500° (?).....	24.91	21.7	4.6		21.22	19.5	2.0	
R <sub>c</sub> , $\frac{1}{20}$ in. thick ¶.....	26.40	23.2	4.0		26.02	22.5		
Same, A 500°.....	18.79	7.6	18.7		19.16	8.8	21.7	
	Cu, 6.91 %				Cu, 8.08 %			
G <sub>s</sub> , to shape.....	9.67	8.2	2.0	1.6	11.65	10.2		2.0
Same { 450° C <sub>s</sub> .....	9.18	9.1		1.2	11.15	9.3		1.6
450° Q <sub>w</sub> .....	12.14	9.6	3.0	1.6	12.65	12.0	3.0	1.7
G <sub>m</sub> , 1 in. diam.....	14.84	9.6	4.0	4.6	16.76	11.3		1.6
R <sub>h</sub> , $\frac{5}{4}$ in. diam.....	24.21	14.2	13.5	11.5	23.08	13.2	17.5	23.3
R <sub>h</sub> , $\frac{7}{8}$ in. diam.....	25.28	19.2	14.5	27.6	24.11	17.3	17.5	27.6
D <sub>c</sub> , $\frac{9}{8}$ in. diam.....					25.9	24.3	5.5	15.0

Treatment	% Cu**				
	10.7	16.0	19.9	29.0	31.7
G <sub>s</sub> , to shape.....	UTS 10.51	11.52	10.61	9.92	9.45
G <sub>m</sub> , 1 in. diam.....	13.68	9.86	11.64	14.86	14.26

\* Prepared from notch bar Al of analysis: Al (by diff.), 99.54; Si, 0.25; Fe, 0.14; Na, 0.07.

† Test pieces, 2 in.  $\times$  0.564 in. diam. for rounds and 3 in.  $\times$  1 in. wide for sheet.

‡ Also true for alloys containing >3.76 % Cu.

§ For 3.76 % Cu, D<sub>c</sub> to  $\frac{2}{3}$  in. diam.

|| Broke outside gage marks.

¶ Extra annealing at 0.07 in. thickness.

\*\* El<sub>a</sub> = 0.0 for all.







## Al-Cu-Ni-Mg-Si.—(Continued)

Treatment	UTS	YP	PL	El <sub>a</sub>	RA	Lit.
R <sub>h</sub> , $\frac{7}{8}$ in. diam.....	27.7	18.9		20	30	(23)
Same, Trt 530°.....	38.6	24.3	12.1	25	33	
Rivet, $\frac{3}{8}$ in. diam., Trt 520°.....	40.3	24.7		25†	26	
Sheet: 0.05 in. { Trt 520°.....	41.0	27.1		19	PS†	
thick { R <sub>e</sub> , Trt 520°.....	42.4	25.2	15.4	18	27.6	
0.018 in. thick, R <sub>e</sub> , Trt 520°.....	44.1	33.1		17	29.9	
0.064 in. Trt, A 350–400°.....	25.2	12.6		16		
Al, 90.9; Cu, 4.0; Ni, 2.12; Mg, 1.56; Fe, 0.42; Si, 1.03 "Y" alloy						
G <sub>s</sub> } 1 in. diam. bars.....	17.3		7.9	1.0		(1)
G <sub>m</sub> } 1 in. diam. bars.....	20.3		8.3	1.0		
Al, 92.3; Cu, 4.04; Ni, 1.77; Mg, 1.47; Fe, 0.20; Si, 0.20						
G <sub>s</sub> } 1 in. diam.....	17.3			2		(1)
G <sub>m</sub> } 1 in. diam.....	21.8			2		
Al, 88; Cu, 8.02; Ni, 1.98; Mg, 1.46; Fe, 0.20; Si, 0.20						
G <sub>s</sub> } 1 in. diam.....	16.85			0.5		(1)
G <sub>m</sub> } 1 in. diam.....	18.9			0.5		

\* Nominal content.

† On 1 in.

‡ Stress at  $\Delta l = \frac{1}{2}\%$   $l_0$ .

## Al-Cu-Zn-Sn

% composition	Trt*	UTS	YP	PL	El <sub>a</sub>	Lit.
Cu, 6.79; Zn, 0.96; Sn, 0.83; Fe, 0.25; Si, 0.20 "L 11"	G <sub>s</sub>	11.0	5.5		3.0	(1)
	G <sub>m</sub>	9.3	6.3		2.0	
Cu, 6–8; Zn, $\geq 1.0$ ; Sn, 0.5–2.0; Fe, $\geq 1$ ; Si, $\geq 1$ "L 11"	G <sub>s</sub>	13.1		1.9	3.0	(1)
	G <sub>m</sub>	13.1		2.4	3.0	
Cu, 9; Sn, 2.0; Zn, 1.5; Fe, $\geq 1$ ; Si, $\geq 1$	G <sub>s</sub>	11.2			1	(1)
	G <sub>m</sub>	17.3			3	

\* Bars 1 in. diam.

## Al-Mg-Si and Al-Mn

Nominal % composition	Treatment	UTS	YP	PL	El*	RA	Lit.
Mg, 0.60; Si, 1.0.....	R, 75 % reduction	A 10.90	3.5	2.1	30.0		(11)
	Trt	34.50	24.6	11.2	18.0		
Mn, 1.2.....	R, 75 % reduction	A 12.30	4.9	2.1	40.0		(11)
	H	20.38	16.2	8.4	10.0		

\* Gage length = 4 × diam.

## Al-Zn(25)

Treatment* (diam. in.)	UTS	YP	El <sub>a</sub>	RA
Zn, 5.21 %				
G <sub>s</sub> , 1.....	8.2	4.25	16.0	
G <sub>m</sub> , 1.....	10.4	4.4	29.0	
R <sub>h</sub> , $\frac{5}{4}$ .....	11.8	6.8	33	67
R <sub>h</sub> , $\frac{7}{8}$ .....	14.1	11.65†	26	66
A 400°.....	10.0	4.1	43	77
D <sub>d</sub> , $\frac{13}{16}$ .....	15.4	14.3†	19.5	65.8
Zn, 9.27 %				
G <sub>s</sub> , 1.....	13.4	7.9	9.0	
G <sub>m</sub> , 1.....	12.3	6.1	11.0	
R <sub>h</sub> , $\frac{5}{4}$ .....	14.8	7.7	36	70
R <sub>h</sub> , $\frac{7}{8}$ .....	16.35	10.1	33	67
R <sub>h</sub> , $\frac{1}{2}$ .....	17.6	11.0	38†	68.3
D <sub>d</sub> , $\frac{13}{16}$ .....	17.5	15.4	19.0	56.5
D <sub>d</sub> , $\frac{7}{8}$ .....	25.7	23.1	7.5	
Zn, 11.0 %				
G <sub>s</sub> , 1.....	14.8	10.1	8.0	
G <sub>m</sub> , 1.....	16.1	7.9	16.0	
R <sub>h</sub> , $\frac{7}{8}$ .....	17.85	8.2	38	64
R <sub>h</sub> , $\frac{1}{2}$ .....	21.7	14.8	33†	63.7
D <sub>d</sub> , $\frac{7}{8}$ .....	29.8	26.5	13.0	
Zn, 13.69 %				
G <sub>m</sub> , 1.....	16.85	7.7	10.5	

## Al-Zn(25).—(Continued)

Treatment* (diam. in.)	UTS	YP	El <sub>a</sub>	RA
Zn, 13.24 %				
G <sub>s</sub> , 1.....	16.7	13.4	4.0	
R <sub>h</sub> , $\frac{5}{4}$ .....	21.5	9.6	35	59
R <sub>h</sub> , $\frac{7}{8}$ .....	22.6	11.0†	31	52
A 400°.....	17.8	5.6	37	63.7
D <sub>d</sub> , $\frac{13}{16}$ .....	23.2	20.2†	19.0	43.5
Zn, 14.29 %				
G <sub>m</sub> , 1.....	18.4	9.1	8.5	
Zn, 15.05 %				
G <sub>s</sub> , 1.....	17.5	15.1	2.0	
R <sub>h</sub> , $\frac{5}{4}$ .....	25.8	10.7	33	53
R <sub>h</sub> , $\frac{7}{8}$ .....	26.05	13.4†	32	54
A 400°.....	21.0	6.7	37	60.4
R <sub>h</sub> , $\frac{1}{2}$ .....	28.2	18.3	31†	58.5
D <sub>d</sub> , $\frac{13}{16}$ .....	26.0	17.5†	20	42.1
Zn, 16.08 %				
G <sub>s</sub> , 1.....	20.0	17.3	3.5	
G <sub>m</sub> , 1.....	18.0	8.35	6.5	
R <sub>h</sub> , $\frac{7}{8}$ .....	25.2	11.65	31	58
Zn, 16.85 %				
G <sub>s</sub> , 1.....	19.1	16.1	1.0	
G <sub>m</sub> , 1.....	21.4	9.1	5.0	
R <sub>h</sub> , $\frac{5}{4}$ .....	31.3	20.8	22	36
R <sub>h</sub> , $\frac{7}{8}$ .....	28.5	17.8†	25	45
D <sub>d</sub> , $\frac{13}{16}$ .....	30.9	27.4	13	24.5
Zn, 18.39 %				
G <sub>m</sub> , 1.....	21.6	13.9	7.0	
Zn, 19.67 %				
G <sub>s</sub> , 1.....	20.8	19.5	2.5	
R <sub>h</sub> , $\frac{7}{8}$ .....	31.9	19.5	21	47
R <sub>h</sub> , $\frac{1}{2}$ .....	34.4	25.6	30†	54.7
D <sub>d</sub> , $\frac{7}{8}$ .....	40.4	24.8	9.0	
Zn, 20.15 %				
G <sub>s</sub> , 1.....	20.6	15.75	1.0	
G <sub>m</sub> , 1.....	21.7	12.3	4.0	
R <sub>h</sub> , $\frac{5}{4}$ .....	35.7	27.3	20	36
R <sub>h</sub> , $\frac{7}{8}$ .....	33.7	19.5†	26	46
A 400°.....	29.5	18.6	22	27.5
D <sub>d</sub> , $\frac{13}{16}$ .....	35.1	31.4†	13	26.5
Zn, 22.74 %				
G <sub>m</sub> , 1.....	21.3	14.3	3.5	
Zn, 24.50 %				
G <sub>s</sub> , 1.....	25.7		1.0	
R <sub>h</sub> , $\frac{7}{8}$ .....	39.0	31.2	20	39
R <sub>h</sub> , $\frac{1}{2}$ .....	37.8	32.0	27†	46.6
D <sub>d</sub> , $\frac{7}{8}$ .....	42.4	38.1	7.0	
Zn, 26.05 %				
G <sub>s</sub> , 1.....	27.3	17.6	2.0	
G <sub>m</sub> , 1.....	27.9	16.7	4.0	
R <sub>h</sub> , $\frac{5}{4}$ .....	42.7	39.4	16	28
R <sub>h</sub> , $\frac{7}{8}$ .....	37.6	31.8†	20	41
D <sub>d</sub> , $\frac{7}{8}$ .....	42.2	34.7†	8.0	
Zn, 30.23 %				
{ G <sub>s</sub> } 1 in. diam.....		26.1	12.8	1.5
{ G <sub>m</sub> } 1 in. diam.....		28.2	16.2	3.0
Zn, 36.02 %				
{ G <sub>s</sub> } 1 in. diam.....		27.9	18.4	0.5
{ G <sub>m</sub> } 1 in. diam.....		27.6	21.4	0.5



Al-Zn (25).—(Continued)

% Zn	Treatment	UTS	YP	El <sub>a</sub>
40.27	$\left\{ \begin{matrix} G_s \\ G_m \end{matrix} \right\}$ 1 in. diam. ....	$\left\{ \begin{matrix} 28.8 \\ 25.7 \end{matrix} \right\}$	$\left\{ \begin{matrix} 18.3 \\ 17.5 \end{matrix} \right\}$	$\left\{ \begin{matrix} 1.0 \\ 0.5 \end{matrix} \right\}$
44.75	$\left\{ \begin{matrix} G_s \\ G_m \end{matrix} \right\}$ 1 in. diam. ....	$\left\{ \begin{matrix} 29.1 \\ 30.1 \end{matrix} \right\}$	$\left\{ \begin{matrix} 14.2 \\ 15.3 \end{matrix} \right\}$	$\left\{ \begin{matrix} 5.0 \\ 1.0 \end{matrix} \right\}$
49.66	$\left\{ \begin{matrix} G_s \\ G_m \end{matrix} \right\}$ 1 in. diam. ....	$\left\{ \begin{matrix} 29.5 \\ 34.0 \end{matrix} \right\}$	$\left\{ \begin{matrix} 20.5 \\ 8.0 \end{matrix} \right\}$	$\left\{ \begin{matrix} 4.0 \\ 1.0 \end{matrix} \right\}$

\* Diameters after specified mechanical treatment given, test pieces 0.564 in. diam.

† PL's of specimens are as follows:

Trt	% Zn	5.21	13.24	15.05	16.85	20.15	26.05
R <sub>h</sub> , $\frac{7}{8}$ in. ....		7.9	9.4	11.0	12.6	15.8	24.4
D <sub>d</sub> , $\frac{1}{8}$ in. ....		10.2	13.4	15.8		25.2	

† El on 1 in.

Al-Zn (24)

Sand cast 2 cm diam.			
% Zn	UTS	PL	El
10	11.0	4.4	7.5
20	14.2	5.0	2
31.6	17.8	5.0	1
40.6	21.4	12.9	1
50.7	19.5	13.7	0.5

Forged 2 cm diam. from 5 cm diam. G <sub>m</sub> billets								
% Zn	As forged				Annealed 300°/1 h			
	UTS	PL	El	RA	UTS	PL	El	RA
5.3	12.9	10.9	19	64	9.1	2.4	30	74
10.2	17.2	10.1	34	55	14.0	4.3	38	65
16	23.9	17.2	23	47	21.9	7.1	28	41
21	29.6	21.1	14	27	29.8	10.7	15	37

Al-Zn-Cu (26)

Treatment	UTS	YP	El <sub>a</sub>	RA
Zn, 3.50; Cu, 2.31				
G <sub>s</sub> , 0.56 in. diam. ....	13.7	6.3	12	
G <sub>m</sub> , 1 in. diam. ....	15.0	2.8	23	
R <sub>h</sub> , $\frac{5}{4}$ in. diam. ....	18.9	12.0	27	56.8
R <sub>h</sub> , $\frac{7}{8}$ in. diam. ....	17.3	10.4	29	61.6

Zn, 4.76; Cu, 0.87

G <sub>s</sub> , 0.56 in. diam. ....	11.0	4.1	13	
G <sub>m</sub> , 1 in. diam. ....	12.6	4.25	25	
R <sub>h</sub> , $\frac{5}{4}$ in. diam. ....	16.4	9.9	29	64.0
R <sub>h</sub> , $\frac{7}{8}$ in. diam. ....	18.9	14.2	22	61.6

Zn, 4.71; Cu, 2.67

G <sub>s</sub> , 0.56 in. diam. ....	13.5	3.9	7	
G <sub>m</sub> , 1 in. diam. ....	16.2	7.4	14	
R <sub>h</sub> , $\frac{5}{4}$ in. diam. ....	20.8	11.5	25	44.8
R <sub>h</sub> , $\frac{7}{8}$ in. diam. ....	18.6	11.5	26	50.8

Zn, 4.64; Cu, 3.92†

G <sub>s</sub> , 0.56 in. diam. ....	12.9	7.25	4	
G <sub>m</sub> , 1 in. diam. ....	18.4	4.6	14	
R <sub>h</sub> , $\frac{5}{4}$ in. diam. ....	22.2	11.7	23	39.2
R <sub>h</sub> , $\frac{7}{8}$ in. diam. ....	20.9	13.2	20	42

Zn, 7.38; Cu, 1.76

G <sub>s</sub> , 0.56 in. diam. ....	15.6	7.9	10	
G <sub>m</sub> , 1 in. diam. ....	15.9	5.2	19	
R <sub>h</sub> , $\frac{5}{4}$ in. diam. ....	20.5	12.8	25	64.0
R <sub>h</sub> , $\frac{7}{8}$ in. diam. ....	20.6	12.3*	30	57.2

Al-Zn-Cu (26).—(Continued)

Treatment	UTS	YP	El <sub>a</sub>	RA
Zn, 9.91; Cu, 0.94				
G <sub>s</sub> , 0.56 in. diam. ....	16.2	9.1	8	
G <sub>m</sub> , 1 in. diam. ....	16.9	7.4	19	
R <sub>h</sub> , $\frac{5}{4}$ in. diam. ....	20.5	9.5	29	59.2
R <sub>h</sub> , $\frac{7}{8}$ in. diam. ....	21.4	12.4*	24	50.8

Zn, 9.96; Cu, 2.75

G <sub>s</sub> , 0.56 in. diam. ....	18.0	10.2	6	
G <sub>m</sub> , 1 in. diam. ....	20.2	7.6	11	
R <sub>h</sub> , $\frac{5}{4}$ in. diam. ....	26.3	15.0	23	39.2
R <sub>h</sub> , $\frac{7}{8}$ in. diam. ....	26.8	15.1*	24	42

Zn, 13.99; Cu, 1.64

G <sub>s</sub> , 0.56 in. diam. ....	22.7	9.8	4	
G <sub>m</sub> , 1 in. diam. ....	23.9	9.9	16	
R <sub>h</sub> , $\frac{5}{4}$ in. diam. ....	33.7	17.0	23	36.4
R <sub>h</sub> , $\frac{7}{8}$ in. diam. ....	32.8	19.8	24	54.8

Zn, 14.74; Cu, 2.50

G <sub>s</sub> , 0.56 in. diam. ....	22.2	15.3	3	
G <sub>m</sub> , 1 in. diam. ....	21.6	9.3	6.5	
R <sub>h</sub> , $\frac{5}{4}$ in. diam. ....	37.3	23.3	21	33.6
R <sub>h</sub> , $\frac{7}{8}$ in. diam. ....	33.1	19.8*	20	36.4

Zn, 18.45; Cu, 0.80†

G <sub>s</sub> , 0.56 in. diam. ....	23.1	11.7	4	
G <sub>m</sub> , 1 in. diam. ....	22.4	13.1	2	
R <sub>h</sub> , $\frac{5}{4}$ in. diam. ....	38.9	30.1	22	39.2
R <sub>h</sub> , $\frac{7}{8}$ in. diam. ....	38.1	26.0*	24	39.2

Zn, 18.95; Cu, 1.66

G <sub>s</sub> , 0.56 in. diam. ....	25.4	18.3	3	
G <sub>m</sub> , 1 in. diam. ....	29.1	12.8	11	
R <sub>h</sub> , $\frac{5}{4}$ in. diam. ....	39.9	32.9	21	39.2
R <sub>h</sub> , $\frac{7}{8}$ in. diam. ....	38.1	25.8*	24	36.4

Zn, 23.48; Cu, 2.67

G <sub>s</sub> , 0.56 in. diam. ....	28.7	8.8	2	
G <sub>m</sub> , 1 in. diam. ....	31.8	10.1	4	
R <sub>h</sub> , $\frac{5}{4}$ in. diam. ....				
R <sub>h</sub> , $\frac{7}{8}$ in. diam. ....	46.6	31.7	18	33.5

\* Values of PL are:

% Zn. ....	7.38	9.91	9.96	14.74	18.45	18.95
% Cu. ....	1.76	0.94	2.75	2.50	0.80	1.66
PL. ....	8.7	12.6	13.7	18.9	20.6	1.92

† Contains also Fe, 0.10; Si, 0.14.

‡ Contains also Fe, 0.16; Si, 0.12.

Commercial Al-Zn-Cu

% composition	Treatment	UTS	YP	PL	El <sub>a</sub>	Lit.
Al, 80.5–85; Zn, 12.5–14.5; Cu, 2.5–3, "L 5" alloy						
Zn, 12.5–14.5; Cu, 2.5–3; Fe, > 1; Si, > 1 (v. Fig. 5)	G <sub>s</sub> , 1 in. diam.	16.5		2.8	2	(1)
	G <sub>s</sub> new, $\frac{5}{8}$ in. diam. { 22 tests (12 melts)	17.3–23.3			2–4	(5)
		20.6 (mean)			3	(5)
Zn, 12.58; Cu, 2.69*	G <sub>m</sub> , 1 in. diam.	19.4		4.4	4	(1)
	G <sub>m</sub> new, $\frac{5}{8}$ in. diam. { 24 tests (12 melts)	18.3–23.3			4–7	(5)
		20.8 (mean)			5.0	(5)
Zn, 13.5; Cu, 2.5*†	G <sub>s</sub> { new, 1 in. diam. (for max. IS)	19.1			5	(1)
	G <sub>m</sub> { new, 1 in. diam. }	18.7			7	
	G <sub>s</sub> { new, 1 in. diam. }	16.5	7.1		4.0	(23)
	G <sub>m</sub> { new, 1 in. diam. }	20.5	7.1		5.0	

Commercial Al-Zn-Cu.—(Continued)

% composition	Treatment	UTS	YP	PL	El <sub>a</sub>	Lit.
Al, 77; Zn, 20; Cu, 3 "A" alloy						
Zn, 20; Cu, 3; Fe, 0.20; Si, 0.20	R <sub>h</sub> , 1½ in. diam.	42.5	28.4	19.5	17½	(23)
	Same, A 200°C	39.1	23.6		21	
	R <sub>h</sub> , ¾ in. diam.	42.5	28.8		21½	
	R <sub>h</sub> , 0.104–0.048 in. thick	42.8	26.6	PS   = 28–33	19	
	Same, A 200°C	35.0	19.4		26	
	R <sub>c</sub> , 0.104–0.048 in. thick	46.8	41.0		11	
	D, 0.063 in. diam.	43.8			8	
	Same, A 250°	32.6			14 <sub>c</sub>	
	D, 0.0125 in. diam.	43.0			2	
	Same, A 250°	32.6				
Zn, 20.52; Cu, 3.13	G <sub>s</sub> , 5 in. diam.	43.6	28.8		19	
	E, 2½ in. diam.					
	E, 1½ in. diam.	41.1	24.9		22	
	R <sub>h</sub> , ¾ in. diam.	43.0	27.1		17	
	R (rod) C (–80°/10 m)	46.2	29.8		13.0	(26)
	J					

\* Contains Fe, 0.20; Si, 0.20.

† Nominal composition.

‡ RA = 30 %.

§ RA = 36 %.

|| Δl = ½ % l<sub>0</sub>.

## Al-Zn-Cu-Fe and Al-Zn-Cu-Mg-Mn

Treatment	UTS	YP	PL	El <sub>a</sub>	RA	Lit.
Al, 86.5; Zn, 10.0; Cu, 2.0; Fe, 1.5 (nominal)						
G <sub>s</sub> , 2 × ½ in. diam.	19.1	8.5*	4.9	4.0		(11)
Al; Zn, 18; Cu, 2.5; Mg, 0.35; Mn, 0.35† "G" alloy						
R <sub>h</sub> , 0.04–0.05 in. thick 400° Q	54.5	48.2	38–39.5*	19		(23)
E, 4 × ¾ in. R <sub>h</sub> , same	52.0	40.2		17		
Al; Zn, 20; Cu, 2.5; Mg, 0.5; Mn, 0.5 "E" alloy‡						
R <sub>h</sub> , ¾ in. diam.	46.8	37.3		15		(23)
Same, 350° Q	59.6	51.8	34.8	12	13.4	
E, ¾ in., R <sub>h</sub> , ¾ in., 400° Q	64.1	34.0		9		
R <sub>h</sub> , 0.04–0.05 in. thick	51.0	38.6		18		
Same, A 250°	39.8	22.8		20		
Same, 400° Q	60.2	46.2	44–49*	15		
E, ¾ in., R <sub>h</sub> , 0.04–0.05 in., 400° Q	61.4	31.5		12		
R (rod) C (–80°/10 m) J	69.0	55.8		13.0		(27)
R <sub>h</sub> , ¾ in. diam.	56.7	38.9		16	21.4	(24)
R <sub>h</sub> , 0.04–0.05 in. thick	55.8	47.9	39–44*	19		
E, 4 × ¾ in., same	52.8	45.7		15		

\* Stress to produce set of ½ % l<sub>0</sub>.

† Contains also Fe, 0.20; Si, 0.75, otherwise similar to "E" alloy.

‡ Contains Fe, 0.20; Si, 0.20.

TABLE 2.—COMPRESSION TESTS

% composition*	Treatment†	UCS	PL <sub>C</sub>	Lit.
Al, 99.24.....	R, ¾ in.	18.00	8.0	(22)
Al, 99.20.....	R <sub>d</sub> , 75%	ca. 16	YP ca. 13	(11)
	R, 75% A	ca. 10	YP ca. 3	
Al (% = ?).....	G	47		(6)
Cu, 8 "L 11"....	G <sub>s</sub>	49		(11)
Cu, 3.25; Mg, 0.7; Mn, Tr.; Fe, 0.28; Si, 0.28	R, ½–1, N	35.2	14.66	(21)
	Same, 495°	35.2	12.15	
	QV† 370°/20 C <sub>f</sub>	18.7	4.82	
Duralumin§.....	R, 1 in. sq.	CS = 50.4 Δl = –14% l <sub>0</sub>		(23)

% composition*	Treatment†	UCS	YP <sub>C</sub>	Lit.
Zn, 9.27.....	R <sub>h</sub> , ¾ in.	13.95	11.5	(25)
Zn, 11.0.....	G <sub>s</sub> , 1 in.		12.6	(25)
	R <sub>h</sub> , ¾ in.	14.5	10.2	

TABLE 2.—COMPRESSION TESTS.—(Continued)

% composition*	Treatment†	UCS	YP <sub>C</sub>	Lit.
Zn, 14.29.....	G <sub>s</sub> , 1 in.		16.1	(25)
Zn, 15.05.....	R <sub>h</sub> , ¾ in.	19.4	14.3	(25)
Zn, 16.08.....	G <sub>s</sub> , 1 in.	25.5	21.7	(25)
	G <sub>m</sub> , 1 in.	18.9	14.0	
	R <sub>h</sub> , ¾ in.	24.3	17.2	
Zn, 19.67.....	G <sub>m</sub> , 1 in.	28.5	23.9	(25)
	R <sub>h</sub> , ¾ in.	28.9	25.7	
Zn, 20.15.....	G <sub>s</sub> , 1 in.	28.7	26.2	(25)
Zn, 22.74.....	G <sub>m</sub> , 1 in.	26.8	23.3	(25)
Zn, 24.50.....	G <sub>s</sub> , 1 in.	31.0	28.2	(25)
	R <sub>h</sub> , ¾ in.	36.7	33.2	
Zn, 30.23.....	G <sub>m</sub> , 1 in.	31.3	26.6	(25)
Zn, 40.27.....	G <sub>m</sub> , 1 in.	32.9	31.8	(25)
Zn, 44.75.....	G <sub>m</sub> , 1 in.	38.0	29.8	(25)
Zn, 55.07.....	G <sub>s</sub> , 1 in.	30.9	29.8	(25)
	G <sub>m</sub> , 1 in.	37.2	36.2	
Zn, 10; Cu, 2; Fe, 1.5	G <sub>s</sub> (new)	66		(11)
Zn, 20; Cu, 3; Fe, 0.20; Si, 0.20 "A"			PL <sub>C</sub>	
	R <sub>h</sub> , 1½ in.	20.8	15.0	(23)
	E, ¾, R <sub>h</sub> , ¾ in.	23.0	18.1	
	E, 1¼ in.	19.5	14.2	
	E, 2 in.	¶	14.9	

\* % Al by difference.

† Dimensions are diameters, unless marked otherwise.

‡ W 495°/30 Q<sub>b</sub> V.

§ Cu, 3.5–4.5; Mn, 0.4–0.7; Mg, 0.4–0.7; Fe, 0.75, Si, 0.60.

|| Test pieces 2.75 in. × 0.5 in. diam.

¶ Length ≥ 4 × diam.

TABLE 3.—SHEAR AND TORSION TESTS

% composition*	Treatment†	USS	PL <sub>S</sub> ‡	Lit.
Al, 99.24.....	R, ¾ in.	9.7		(22)
Al, 99.20.....	Wk <sub>d</sub> , 75%	7.7		(11)
	Same, A	7.0		
Al (% = ?).....	G	8.4		(6)
	R	11.2		
Cu, 3.25; Mg, 0.70; Mn, Tr.; Fe, 0.28; Si, 0.28	R, ½–1, N	20.5		(21)
	RW 495°/30 Q <sub>b</sub>	30.4§	13.3	
	2 h V	18.7		
	RW 370°/20 C <sub>f</sub>	33.2§	9.9	
Cu, 4.5; Mn, 0.70; Si, 0.80	Wk, A	11.2		(11)
	Wk, Trt	25.3		
Cu, 3.85; Mg, 0.8; Mn, 0.4; Fe, 0.5; Si, 0.9; Zn, 0.04	G <sub>m</sub> , 3.5 mm	15.4		(15)
	Same, Trt	22.4		
Duralumin ¶.....	G <sub>s</sub> , 42 mm Trt	24.3		
	Wk	30.0		(9)
Duralumin**.....	D, ½ in.	25.9		(23)
Mg, 0.60; Si, 1.0 ...	Wk, A	7.7		(11)
	Wk, Trt	23.2		
Mn, 1.2.....	Wk, A	9.1		(11)
	Wk, H	10.5		
Zn, 9.27.....		16.3‡		(25)
		19.5‡		
		22.8‡		
		32.5‡		
Zn, 11.0.....	R <sub>h</sub> , 1¼ in.			
Zn, 24.50.....	R <sub>h</sub> , 1¼ in.	32.5‡		(25)



TABLE 3.—SHEAR AND TORSION TESTS.—(Continued)

% composition*	Treatment†	USS	PLS‡	Lit.
Zn, 10.....	G <sub>s</sub> , 2 cm	6.05		(24)
20.....		9.0		
31.6.....		10.1		
40.6.....		10.4		
50.7.....		9.9		
Zn, 13.5; Cu, 2.5††	G <sub>m</sub> , 1 in.	20.2‡‡		(23)
Zn, 20; Cu, 3; Fe, 0.20; Si, 0.20; "A" alloy	R <sub>h</sub> , 1 $\frac{3}{8}$ in.	34.2‡	9.46	(23)
	R <sub>h</sub> , 0.046 in.	34.5‡‡		
	R <sub>h</sub> , 0.061 in.	36.7‡‡		
	D <sub>d</sub> , 0.063 in.	27.3		
	Same, A 250°	27.7		

\* % Al by difference.

† Dimensions are diameters unless marked otherwise.

‡ From torsion test.

§ Torsional modulus of rupture. || Thickness.

¶ Alloy 681 A: Cu, 3.5–5.5; Mn, 0.5–0.8; Mg, 0.5.

\*\* Rivet wire: Cu, 3.92; Mn, 0.51; Mg, 0.37; Fe, 0.36; Si, 0.41.

†† Contains Fe, 0.2; Si, 0.2.

‡‡ Punching test.

TABLE 4.—HARDNESS

% composition*	Treatment†	BHN	d-P‡	ScH§	Lit.
Al, 99.97.....	Wk, A	16	B		(10)
Al, 99.24; Fe, 0.5; Cu; Si	R, $\frac{3}{4}$ in.	45	B		(22)
Al, 99.20.....	G <sub>s</sub> , $\frac{1}{2}$ in.	23	B		(11)
	Wkd, 75 %	39	B	17	
	Same, A	25	B	6	
Al, <99.00.....	G <sub>s</sub>	21–24	B	6–9	(6)
	Sheet, A	22–26	B	4–6	
Al, 99.07–98.46; Fe, 0.70–0.98; Si, 0.23–0.56	10 mm    A	25	B		(14)
	Same, Wkc 150–200 %	41	B		
	1 mm    A			4.5	
	Same, Wkc { 50 % 300 %			16	
				28	
	2 mm    A			5.5	
	Same, Wkc { 50 % 300 %			11.5	
				16	
Cu, 4.0 (nom.).....	G <sub>s</sub> , $\frac{1}{2}$ in.	70–75	B		(11)
Cu, 4.5; Fe, 0.20; Si, 0.20 (nominal)	G <sub>s</sub> } 1 in. V 8 mo. {	46	B		(23)
	G <sub>m</sub> }	49	B		(23)
	RW 510° Q Tp 160°¶	100	B		(16)
Cu, 8.00 "L 11".....	G <sub>s</sub> , $\frac{1}{2}$ in.	65	B		(11)
Cu, 11–13 "L 8"***	G <sub>s</sub> , 1 in.	67–91	B		(1)
	G <sub>m</sub> , 1 in.	80–84	B		
Cu, 12.48 "L 8" ††	G <sub>s</sub> , 1 in.	81	B	LCH	(1)
	G <sub>m</sub> , 1 in.	67, 74	B	87, 94	
Cu, 4.0; Mg, 0.5 (nom); Fe, 0.20.....	G <sub>s</sub> , 1 in.	55	B		(1)
				ScH§	
Cu, 3.5; Mg, 0.7; Mn, Tr.; Fe, 0.28; Si, 0.28	R $\frac{1}{2}$ –1, N	100	B	19	(21)
	495° Qb V	100	B	22	
	370° Cf	50	B	12	
Cu, 4.5; Mn, 0.7; Si, 0.8	Wk, A	43	B	15	(11)
	Wk, Trt	95	B	30	
Duralumin††.....	7 mm    "H"	98	D		(9)
	Same, "681 D"	125	D		
Duralumin§§.....	10 mm    { 475° Q A 350°	85 45	A B		(14)
Cu, 4.0; Ni, 2.0; Mg, 1.5; Fe, 0.20; Si, 0.20 "Y" alloy	G <sub>s</sub> , 1 in.	88, 91	B		(23)
	Same, Trt	107	B		
	G <sub>m</sub> , 1 in.	83, 88	B		
	Same, Trt	102–106	B		
	R <sub>h</sub> , $\frac{7}{8}$ in., Trt	96	B		
	in.   , Trt	109	E		
Cu, 4.0; Ni, 2.12; Mg, 1.56; Fe, 0.42; Si, 1.03 "Y" alloy	G <sub>s</sub> , 1 in.	70, 73			(1)
	Same, J { 200° 300° 400°	60, 62			
		45, 47			
		17, 17			
	G <sub>m</sub> , 1 in.	76			
	Same, J { 200° 300°	65, 70			
		49, 57			

TABLE 4.—HARDNESS.—(Continued)

% composition*	Treatment†	BHN	d-P‡	LCH	Lit.
Cu, 6.8; Zn, 1.0; Sn, 0.8†† "L 11"	G <sub>s</sub> , 1 in.	60	B	65	(1)
	G <sub>m</sub> , 1 in.	44	B		
Cu, 6–8; Zn, $\frac{3}{4}$ –1; Sn, $\frac{1}{2}$ –2** "L 11"	G <sub>s</sub> , 1 in.	50–55	B		(1)
	G <sub>m</sub> , 1 in.	48–60	B	ScH§	
Mg, 0.6; Si, 1.0 (nominal)	R, 75 % { A Trt	27.0 96.0	B B	9	(11)
Mn, 1.2 (nominal).....	R, 75 % { A H	32.0 50.0	B B	10 20	(11)
Zn, 5.21.....	R <sub>h</sub> , $\frac{1}{4}$ in.	35	C	5.0	(25)
9.27.....	R <sub>h</sub> , $\frac{1}{4}$ in.	56	C	6.7	
13.24.....	R <sub>h</sub> , $\frac{1}{4}$ in.	62	C	9.1	
Zn, 15.05.....	R <sub>h</sub> , $\frac{1}{4}$ in.	88	C		(25)
	R <sub>h</sub> , $\frac{1}{4}$ in.	105	C	15.0	
	R <sub>h</sub> , $\frac{1}{4}$ in.	162	C	18.0	
	R <sub>h</sub> , $\frac{1}{4}$ in.	156	C	25.0	
Zn, 10.....	G <sub>s</sub> , 20 cm	40	A	10.3	(24)
	G <sub>s</sub> , 20 cm	81	A	32	
	G <sub>s</sub> , 20 cm	85	A	30.5	
	G <sub>s</sub> , 20 cm	85	A	34.8	
	G <sub>s</sub> , 20 cm	78	A	36.8	
	G <sub>s</sub> , 20 cm				
Zn, 10.....	G <sub>s</sub> , 20 cm	3.5			(26)
		2.31			
		4.76			
		0.87			
		4.71			
		2.67			
		4.64			
		3.92			
		7.38			
		1.76			
		9.91			
Zn, 12.5–14.5; Cu, 2.5–3** "L 5"	G <sub>s</sub> , 1 in.	9.96			(1)
		2.75			
		14.0			
		1.64			
		14.74			
		2.5			
		18.45			
		0.8			
		18.95			
		1.66			
Zn, 12.58; Cu, 2.69†† "L 5"	G <sub>s</sub> , 1 in.	68	B	77	(1)
		88	B		
Zn, 13.5; Cu, 3.5†† "L 5"	G <sub>s</sub> } 1 in. new {	68	B		(23)
		64	B		
Zn, 20; Cu, 3 ††.....	R <sub>h</sub> , $\frac{1}{4}$ in.	114	B		(23)
Zn, 10; Cu, 2; Mg, 1.5 (nom.).....	G <sub>s</sub> , $\frac{1}{2}$ in.	70	B		(11)

\* % Al by difference.

† Dimensions are diameters unless otherwise indicated.

‡ Ball diameters and loads are as follows: A = 10 mm, 1000 kg; B = 10 mm, 500 kg; C = 9.52 mm, 1000 kg; D = 2.5 mm, 62.5 kg; E = 2 mm, 40 kg.

§ Magnifier hammer used.

|| Thickness.

¶ R<sub>h</sub>,  $\frac{1}{4}$  in. diam., W 510°/1 da, Q V 2 d, Tp 160°/20 h.\*\* Contains Fe,  $\frac{3}{4}$ –1; Si,  $\frac{3}{4}$ –1.

†† Contains Fe, 0.2; Si, 0.2.

‡‡ Cu, 3.5–5.5; Mn, 0.5–0.8; Mg, 0.5.

§§ Cu, 3.5–4; Mn, 0.5–1; Mg, 0.5.

||| Treated at 520°.

¶¶  $\frac{1}{2}$  in. sq. Tp = W 350°/30 C<sub>s</sub>.

TABLE 5.—IMPACT HARDNESS (1)

% composition	Name	Trt	IHN*	
			Cone	10 mm ball
Cu, 12.48; Fe, 0.20; Si, 0.20.....	L 8	{ G <sub>s</sub> G <sub>m</sub>	98–101 100	103–107 105–118
Cu, 4.0; Fe, 2.0; Mg, 1.5†.....		G <sub>s</sub>	113	117
Cu, 6.79; Zn, 0.96; Sn, 0.83; Fe, 0.20; Si, 0.20	L 11	{ G <sub>s</sub> G <sub>m</sub>	70–79 73	69–72 69
Zn, 12.58; Cu, 2.69; Fe, 0.20; Si, 0.20	L 5	{ G <sub>s</sub> G <sub>m</sub>	99 91	103 81

\* IHN = energy of blow (kg-m) ÷ volume of indentation (cm<sup>3</sup>).

† Nominal.

TABLE 6.—IMPACT STRENGTH

% composition*	Treatment†	IS‡ (kg-m)	Lit.
Al, 99.67; Fe, 0.06; Si, 0.25	J { 20° — 20° — 80° — 182°	11.2 <sub>y'</sub> 10.6 <sub>y'</sub> 11.2 <sub>y'</sub> 13.1 <sub>y'</sub>	(6)
Al, 99.24.....	R, $\frac{3}{4}$ in.	32.3 <sub>u</sub>	(22)
Al, 99.1–98.4; Fe, 0.7–1; Si, 0.2–0.56	10 mm thick A Same, Wk { 50% 300%	8–8.5 <sub>y</sub> 5.2 <sub>y</sub> 5.0 <sub>y</sub>	(14)
Cu, 5.7; Fe, 0.2; Si, 0.2..	G <sub>s</sub> , 1 in. G <sub>m</sub> , 1 in.	0.058 <sub>v</sub> .146 <sub>v</sub>	(1)
Cu, 7.75; Fe, 0.2; Si, 0.2 “L 11”	G <sub>s</sub> , 1 in. G <sub>m</sub> , 1 in.	0.028 <sub>v</sub> .095 <sub>v</sub>	(1)
Cu, 11–13; Fe, > 1; Si, > 1 “L 8”	G <sub>s</sub> , 1 in. G <sub>m</sub> , 1 in.	0.087 <sub>u</sub> .090 <sub>u</sub>	(1)
Cu, 12.5; Fe, 0.2; Si, 0.2 “L 8”	G <sub>s</sub> , 1 in. G <sub>m</sub> , 1 in.	0.012 <sub>v</sub> .033 <sub>v</sub>	(1)
Cu, 3.25; Mg, 0.7; Mn, Tr.; Fe, 0.28; Si, 0.28	R $\frac{1}{2}$ –1, N 495°, 100° Q 370°/20 C <sub>f</sub>	1.92 <sub>z</sub> 2.68 <sub>z</sub> 2.39 <sub>z</sub>	(21)
Cu, 2.1; Mn, 1.9.....	R <sub>h</sub> , $\frac{7}{8}$ in.	0.57 <sub>u</sub>	(27)
Cu, 2.9; Mn, 0.9.....	R <sub>h</sub> , $\frac{7}{8}$ in.	0.76 <sub>u</sub>	(27)
Cu, 14.1; Mn, 0.9; Fe, 0.2; Si, 0.2	G <sub>s</sub> , 1 in. G <sub>s</sub> , 1 in.	0.008 <sub>v</sub> .016 <sub>v</sub>	(1)
Cu, 3.5–4; Mg, 0.5; Mn, 0.5–1 “Duralumin”	10 mm thick { 475° Q 475° Q <sub>2</sub> A 350°	3.2 <sub>y</sub> 3.6 <sub>y</sub> 4.0 <sub>y</sub>	(14)
Cu, 3.6; Mg, 0.5; Mn, 0.5; Fe, 0.6; Si, 0.6 “Duralumin”	J { 20° — 20° — 80° — 182°	5.0 <sub>y'</sub> 5.6 <sub>y'</sub> 5.0 <sub>y'</sub> 5.6 <sub>y'</sub>	(6)
Cu, 3; Mn, 1; Mg, 0.5; Fe  ; Si, 1§	R, $\frac{7}{8}$ in. Trt J { 20° 150°	0.76 <sub>v</sub> –0.70 <sub>w</sub> 0.67 <sub>v</sub> –0.68 <sub>w</sub>	(23)
Cu, 5.08; Mn, 0.4; Mg, 0.85; Fe, 0.2; Si, 0.89§	R <sub>h</sub> , $\frac{7}{8}$ in. Trt J { 20° 150° 240°	0.43 <sub>v</sub> –0.33 <sub>w</sub> –1.78 <sub>x</sub> 0.37 <sub>v</sub> –0.30 <sub>w</sub> 0.20 <sub>v</sub> –0.15 <sub>w</sub>	(23)
Cu, 6.25; Mn, 0.47; Mg, 0.79; Fe  ; Si, 1.17§	R <sub>h</sub> , $\frac{7}{8}$ in. Trt J { 20° 150° 240°	0.32 <sub>v</sub> –0.23 <sub>w</sub> –1.24 <sub>x</sub> 0.30 <sub>v</sub> –0.24 <sub>w</sub> 0.16 <sub>v</sub> –0.11 <sub>w</sub>	(23)
Cu, 2; Ni, 1.47; Mg, 0.95; Mn, 0.4; Fe  ; Si, 0.75¶	R <sub>h</sub> , $\frac{7}{8}$ in. Trt J { 20° 150° 240°	0.39 <sub>v</sub> –0.27 <sub>w</sub> –1.65 <sub>x</sub> 0.35 <sub>v</sub> –0.25 <sub>w</sub> 0.17 <sub>v</sub> –0.13 <sub>w</sub>	(23)
Cu, 4.0; Ni, 1.77; Mg, 1.47** “Y”	G <sub>s</sub> , 1 in. G <sub>m</sub> , 1 in.	0.017 <sub>v</sub> 0.042 <sub>v</sub>	(1)
Cu, 4; Ni, 2; Mg, 1.5**....	G <sub>m</sub> , Trt	0.50 <sub>u</sub>	(23)
Cu, 4.08; Ni, 2.03; Mg, 1.60; Fe  ; Si, 0.25 “Y”	R <sub>h</sub> , $\frac{7}{8}$ in. Trt J { 20° 150° 240°	0.26 <sub>v</sub> –0.22 <sub>w</sub> –1.20 <sub>x</sub> 0.24 <sub>v</sub> –0.17 <sub>w</sub> 0.15 <sub>v</sub> –0.11 <sub>w</sub>	(23)
Cu, 4.22; Ni, 2.05; Mg, 0.52; Mn, 0.4; Fe; Si††	R <sub>h</sub> , $\frac{7}{8}$ in. Trt J { 20° 150° 240°	0.26 <sub>v</sub> –0.20 <sub>w</sub> –1.16 <sub>x</sub> 0.27 <sub>v</sub> –0.18 <sub>w</sub> 0.21 <sub>v</sub> –0.16 <sub>w</sub>	(23)
Cu, 4.35; Ni, 1.77; Mg, 1.59; Mn, 0.4; Fe; Si††	R <sub>h</sub> , $\frac{7}{8}$ in. Trt J { 20° 150° 240°	0.24 <sub>v</sub> –0.18 <sub>w</sub> –1.05 <sub>x</sub> 0.19 <sub>v</sub> –0.16 <sub>w</sub> 0.13 <sub>v</sub> –0.09 <sub>w</sub>	(23)
Cu, 8; Ni, 2; Mg, 1.46**	G <sub>s</sub> , 1 in. G <sub>m</sub> , 1 in.	0.009 <sub>v</sub> 0.013 <sub>v</sub>	(1)
Cu, 9; Sn, 2; Zn, 1.5§§..	G <sub>s</sub> , 1 in. G <sub>m</sub> , 1 in.	0.18 <sub>u</sub> 0.25 <sub>u</sub>	(1)
Cu, 6.8; Zn, 0.96; Sn, 0.83** “L 11”	G <sub>s</sub> , 1 in. G <sub>m</sub> , 1 in.	0.051 <sub>v</sub> 0.082 <sub>v</sub>	(1)
Cu, 6–8; Zn, > 1; Sn, 0.5–2 “L 11”	G <sub>s</sub> , 1 in. G <sub>m</sub> , 1 in.	0.28 <sub>u</sub> 0.29 <sub>u</sub>	(1)
Zn, 5.21.....	R <sub>h</sub> , $\frac{7}{8}$ in.	0.56 <sub>u</sub>	(25)
9.27.....	R <sub>h</sub> , $\frac{7}{8}$ in.	.60 <sub>u</sub>	
13.24.....	R <sub>h</sub> , $\frac{7}{8}$ in.	.75 <sub>u</sub>	
15.05.....	R <sub>h</sub> , $\frac{7}{8}$ in.	.80 <sub>u</sub>	
16.85.....	R <sub>h</sub> , $\frac{7}{8}$ in.	.80 <sub>u</sub>	
20.15.....	R <sub>h</sub> , $\frac{7}{8}$ in.	.80 <sub>u</sub>	
26.05.....	R <sub>h</sub> , $\frac{7}{8}$ in.	.57 <sub>u</sub>	
Zn, 15.....	J { 20° — 20° — 80° — 180°	11.2 <sub>y'</sub> 11.2 <sub>y'</sub> 10.0 <sub>y'</sub> 9.3 <sub>y'</sub>	(6)

TABLE 6.—IMPACT STRENGTH.—(Continued)

% composition*	Treatment†	IS‡ (kg-m)	Lit.
Zn, 30.....	J { 20° — 20° — 80° — 180°	2.5 <sub>y'</sub> 2.5 <sub>y'</sub> 1.9 <sub>y'</sub> 1.8 <sub>y'</sub>	(6)
Zn, 12.6; Cu, 2.7; Fe; Si** “L 5”	G <sub>s</sub> , 1 in. G <sub>m</sub> , 1 in.	0.146 <sub>v</sub> 0.200 <sub>v</sub>	(1)
Zn, 12.5–14.5; Cu, 2.5– 3§§ “L 5”	G <sub>s</sub> , 1 in. G <sub>m</sub> , 1 in.	0.43 <sub>u</sub>    0.57 <sub>u</sub>	(1)
Zn, 20.3; Cu, 2.9; Fe– Si** “A”	R, $\frac{7}{8}$ in. Trt J { 20° 150°	0.53 <sub>v</sub> –0.47 <sub>w</sub> 0.66 <sub>v</sub>	(23)
Zn, 20; Cu, 2.5; Mg, 0.5; Mn, 0.5 “E”	R, $\frac{7}{8}$ in. Trt J { 20° 150°	0.31 <sub>v</sub> –0.30 <sub>w</sub> 0.44 <sub>v</sub> –0.36 <sub>w</sub>	(23)
Zn, 15.0; Pb, 1.5.....	J { 20° — 20° — 80° — 182°	10.0 <sub>y'</sub> 10.0 <sub>y'</sub> 10.0 <sub>y'</sub> 8.1 <sub>y'</sub>	(6)

\* % Al by difference.

† Dimensions are diameters unless otherwise marked.

‡ Meaning of subscripts (C. S. = Cross section of specimens):

Subscript	Machine	C. S., mm	Notch	Depth, mm	Radius, mm
u	Izod				
v	Charpy	5 × 5	90° V	1	2.3
w	Charpy	5 × 5	45° V	1	0.25
x	Charpy	10 × 10	45° V	2	0.25
y	Charpy	10 × 10	Mesnager	2	1
y'	Guillery	10 × 10	Mesnager	2	1
z	Charpy	10 × 10	USN	5	1

§ Duralumin type.

|| Fe 0.2.

¶ Magnalite type.

\*\* Fe, 0.2; Si, 0.2.

†† Fe, 0.2; Si, 0.79.

‡‡ Fe, 0.2; Si, 0.25.

§§ Fe, &gt; 1; Si, &gt; 1.

||| Unbroken.

TABLE 7.—ELASTIC PROPERTIES

% composition	Treatment*	10 <sup>-2</sup> E	Lit.
Al, 99.24.....	R, $\frac{3}{4}$ in.	71	(22)
Al, 99.20.....	R <sub>d</sub> , 75% Same, A	70 70	(11)
Al (% = ?).....	R or D	68.9	(6)
Cu, 11–13† “L 8”.....	G <sub>s</sub> , 1 in. Same, J 250° G <sub>m</sub> , 1 in.	75–83 57–64 75–84	(1)
Cu, 3.25; Mg, 0.7; Mn, Tr.; Fe, 0.18; Si, 0.28	R, $\frac{1}{2}$ –1, N 495° Q <sub>b</sub> V 370° C <sub>f</sub>	71.2 76.9 75.5	(19)
Cu, 2.1; Mn, 1.9.....	R <sub>h</sub> , $\frac{7}{8}$ in.	73.1	(27)
Cu, 2.9; Mn, 0.9.....	R <sub>h</sub> , $\frac{7}{8}$ in.	75.6	(27)
Cu, 4.5; Mn, 0.7; Si, 0.8....	Wk	70	(11)
Cu-Mn-Mg‡ “Duralumin”	Wk	70.3	(23)
Cu, 4; Ni, 2; Mg, 1.5§ “Y”	G <sub>m</sub> { R <sub>h</sub> } Trt 520° R <sub>h</sub>	{ 76   74¶ 75††	(23)
Cu, 4; Ni, 2.1; Mg, 1.56; Fe, 0.4; Si, 1.0 “Y”	G <sub>s</sub> , 1 in. Same, J 250° G <sub>m</sub> , 1 in. Same, J 250°	74.5 71 76.6 74.5	(1)
Cu, 6–8; Zn, > 1; Sn, 0.5– 2.0† “L 11”	G <sub>s</sub> , 1 in. G <sub>m</sub> , 1 in.	68 64	(1)
Zn, 5.21.....	R <sub>h</sub> , $\frac{7}{8}$ in. D <sub>c</sub> , $\frac{13}{16}$ in.	63.7 63.7	(25)



TABLE 7.—ELASTIC PROPERTIES.—(Continued)

% composition	Treatment*	$10^{-2} E$	Lit.
Zn, 13.24.....	$R_h, \frac{7}{8}$ in.	63.7	(25)
	$D_c, \frac{13}{16}$ in.	63.5	
Zn, 15.05.....	$R_h, \frac{7}{8}$ in.	69.4	(25)
	$D_c, \frac{13}{16}$ in.	62.1	
Zn, 16.85.....	$R_h, \frac{7}{8}$ in.	63.1	(25)
Zn, 20.15.....	$R_h, \frac{7}{8}$ in.	63.1	(25)
	$D_c, \frac{13}{16}$ in.	63.1	
Zn, 26.05.....	$R_h, \frac{7}{8}$ in.	61.9	(25)
Zn, 7.38; Cu, 1.76.....	$R_h, \frac{7}{8}$ in.	70.3	(26)
	$D_c, \frac{13}{16}$ in.	69.4	
Zn, 9.91; Cu, 0.94.....	$R_h, \frac{7}{8}$ in.	67.9	(26)
	$D_c, \frac{13}{16}$ in.	68.4	
Zn, 9.96; Cu, 2.75.....	$R_h, \frac{7}{8}$ in.	68.4	(26)
	$D_c, \frac{13}{16}$ in.	66.4	
Zn, 12.5–14.5; Cu, 2.5–3† “L 5”	$G_s, 1$ in.	68	(1)
	$G_m, 1$ in.	68	
Zn, 14.74; Cu, 2.50.....	$R_h, \frac{7}{8}$ in.	68.4	(26)
Zn, 18.45; Cu, 0.80.....	$R_h, \frac{7}{8}$ in.	67.2	(26)
	$D_c, \frac{13}{16}$ in.	66.8	
Zn, 18.95; Cu, 1.66.....	$R_h, \frac{7}{8}$ in.	67.9	(26)
Zn, 20; Cu, 3† “A”.....	$R_h, 1\frac{5}{8}$ in.	68	(23)
Zn, 20; Cu, 2.5§; Mn, Mg†† “E”	$ER_h, \frac{7}{8}$ in. 350° Q V	69	(23)

% composition	Treatment*	$10^{-2} G$	Lit.
Al, 99.24.....	$R, \frac{3}{4}$ in.	24.2	(22)
Al (% = ?).....	G	25.8	(6)
Cu-Mn-Mg,** “Dura- lumin”	Bar, 1 in. sq.	28	(23)
Cu, 3.25; Mg, 0.7; Mn, Tr.; Fe, 0.28; Si, 0.28.	$R, \frac{1}{2}-1, N$ 495° Q <sub>o</sub> V 370° C <sub>f</sub>	27.0 27.0 27.0	(19)
Zn, 20; Cu, 3§ “A”.....	$R_h, 1\frac{5}{8}$ in.	26.4	(24)

\* Dimensions are diameters.

†  $\frac{7}{8}$  in. diam.† Contains Fe,  $\frac{1}{2}$ ; Si,  $\frac{1}{2}$ .

\*\* Cu, 3.5–4.5; Mn, 0.4–0.7; Mg,

‡ Cu, 3.5–5.5; Mn, 0.5–0.8; Mg, 0.5.

0.4–0.7.

§ Contains Fe, 0.20; Si, 0.20 (nom-  
inal).

†† Each 0.5 %.

‡‡ Sheet,  $\frac{1}{2}$  in. thick.

|| 1 in. diam.

TABLE 8.—SPECIFIC GRAVITY

Al (Commercial)\*

% composition†	Treatment‡	$d_4^t$	Lit.
Al, 99.64; Fe, 0.15; Si, 0.21	$G_m, 4$ in. sq. $R_c, 2-0.02$ in. § Same, A 450°/14 h $D_c$ , wire Same, A	2.703 2.709 2.710 2.703 2.706	(3)
Al, 99.50.....	$D_d$ , No. 10 SWG Same, A	2.703   2.705	(12)
Al, 99.37; Fe, 0.28; Si, 0.35	$D_c, 0.064$ in. $D_c$ , A	2.702 2.705	(3)
Al, 99.33; Fe, 0.38; Si, 0.29	$R_c, 0.080$ in. thick Same, A	2.708 2.709	(3)
Al, 99.25.....	G Liq., 658.7°C Liq., 1000°C	2.727   2.405   2.311	(12)
Al, 99.11; Fe, 0.56; Si, 0.33	$G_m, 4$ in. sq.	2.706	(3)

Chill Cast¶ Commercial Alloys (18, 23)

% composition	Name	$d_4^{20}$
Cu, 11–13; Fe, $\frac{1}{2}$ ; Si, $\frac{1}{2}$ .....	L 8	2.83–2.94
Cu, 4; Fe, 2; Mg, 0.5 (nominal).....		2.80
Cu, 14; Mn, 1.0; Fe, 0.2; Si, 0.2 (nominal)...		2.98
Cu, 4; Ni, 2; Mg, 1.5; Fe, 0.2; Si, 0.2.....	Y	2.79
Cu, 6–8; Zn, $\frac{1}{2}$ ; Sn, 0.5–2**.....	L 11	2.87–2.93
Zn, 12.5–14.5; Cu, 2.5–3**.....	L 5	3.0

Al-Cu (7)

% Cu	Trt	$G_s$ ¶	$G_m$ ¶	$R_h$ ††	$D_c$ ††
0.86		2.72	2.73	2.73	2.73
1.90		2.73	2.75	2.75	2.75
2.77		2.75	2.77	2.77	2.77
3.76		2.77	2.79	2.79	2.79
4.97		2.78	2.81	2.81	
6.15		2.81	2.83	2.83	
6.91		2.82	2.85	2.85	
8.08		2.85	2.88	2.88	

v. also p.  
576.

Al-Zn (25)

% Zn	Trt	$G_s$ ‡‡	$G_m$ ¶	$R_h$ §§	$D_d$ ††
5.21		2.737	2.783	2.800	2.800
9.27		2.810	2.848	2.867	2.868
13.69			2.910	2.944	2.940
13.24		2.914			
14.29			2.956	2.987	2.985
15.05		2.956			
16.85		2.973	3.017	3.029	3.035
20.15		3.061	3.082	3.093	3.088
26.05		3.176	3.208	3.241	
30.23		3.283	3.352		
36.02		3.325	3.424		
40.27		3.414	3.627		
44.75		3.621	3.753		
49.66		3.906	3.920		

Al-Cu-Mn (27)

% Cu	% Mn	Trt	$G_s$ ‡‡	$G_m$ ¶	$R_h$ §§	$D_c$ ††
2.06	1.94		2.71	2.72	2.80	2.77
2.89	0.94		2.67	2.74	2.79	2.79

Al-Zn-Cu (26)

% Zn	% Cu	Trt	$G_s$ ‡‡	$G_m$ ¶	$R_h$ §§
3.50	2.31		2.80	2.81	2.83
4.76	0.87		2.77	2.79	2.80
4.71	2.67		2.82	2.83	2.85
4.64	3.92		2.84	2.84	2.87
7.38	1.76		2.85	2.86	2.88
9.91	0.94		2.86	2.88	2.90
9.96	2.75		2.92	2.94	2.96
13.99	1.64		2.99	3.00	3.02
14.74	2.50		3.02	3.03	3.06
18.45	0.80		3.08	3.09	3.11
18.95	1.66		3.08	3.10	3.12
23.48	2.67		3.22	3.21	3.26

## Wrought Commercial Alloys

% composition	Name	$d_4^{20}$	Lit.
Cu, 3.5-4.5; Mn, 0.5-0.8; Mg, 0.5...		2.75-2.83	(9)
Cu, 4; Ni, 2; Mg, 1.5 ¶¶.....	Y	2.80	(23)
Zn, 20; Cu, 3 ¶¶.....	A	3.10	(23)
Zn, 20; Cu, 2.5; Mg, 0.5; Mn, 0.5...	E	3.10	(23)
Cu, 3.25; Mg, 0.70; Mn, Tr.***.....		2.80	(21)

\* For specific gravity of pure aluminium, v. p. 456.

† % Al by difference.

‡ Dimensions are diameters unless otherwise indicated.

§ Thickness.

|| Corrected to *in vacuo*.

¶ G, 1 in. diam.

\*\* Contains Fe,  $\geq 1$ ; Si,  $\geq 1$ .†† To  $1\frac{3}{16}$  in. diam.

‡‡ G to shape (0.56 in. diam.).

§§ To  $\frac{7}{8}$  in. diam.

||| Duralumin.

¶¶ Contains Fe, 0.2; Si, 0.2.

\*\*\* Contains Fe, 0.28; Si, 0.28.

TABLE 9.—MOLD SHRINKAGE (26)

% composition*	$-100 \frac{\Delta l}{l_0}$
Cu, 12, L 8.....	1.25
Cu, 14; Mn, 1.....	1.21
Cu, 7; Zn, 1; Sn, 1, L 11.....	1.19
Cu, 4; Ni, 2; Mg, 1.5, "Y" alloy (23).....	1.29
Zn, 13.5; Cu, 2.5, L 5.....	1.27

\* Nominal composition, all contain Fe, 0.20 and Si, 0.20 (nominal).

† Bars cast in sand between faces of steel template and measured when cold.

## LITERATURE

(For a key to the periodicals see end of volume)

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PROPERTIES OF ALLOYS OF ALUMINIUM WITH  
Fe, Mg, Mn, Ni, Ni-Cu, Si, AND Si-Cu  
L. AITCHISON

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## MECHANICAL PROPERTIES

Wt. %	$d_4^{20}$	BHN	UTS	$10^{-2} E$	El
Al-Fe (R, A) (8, 13)					
Fe 1	2.73	29	10.7	66	34
2	2.76	33	11.8	66	33
4	2.80	37	12.6	66	29
7	2.85	38	12.6	68	18
11	2.93	44	12.6	68	8
Al-Mg (R, A) (1-3, 13, 14)					
Mg 0.5	2.69	30	10.2	66	36
1.0	2.69	33	12.6	66	35
2.0	2.68	39	15.8	65	33
4.0	2.65	54	18.9	64.5	22
6.0	2.63	69	28.4	63	20
Al-Mg (G <sub>s</sub> ) (1-3, 13, 14)					
Mg 2	2.68	34	12.6	64.5	3
4	2.65	35	12.6	63	3
5	2.63	36	14	63	3
10	2.57	40	16	61.5	3

## MECHANICAL PROPERTIES.—(Continued)

Wt. %	$d_4^{20}$	BHN	UTS	$10^{-2} E$	El
Al-Mg (G <sub>m</sub> ) (1-3, 13, 14)					
Mg 2	2.68	40	19	64.5	2
4	2.65	60	19.5	63	2
5	2.63	65	19.5	63	2
10	2.57	80	22	61.5	2
Al-Mn (R, A) (3, 13)					
Mn 0.5	2.71	30	11	66	33
1.0	2.73	33	12.5	66	30
1.5	2.75	35	12.5	66	28
2.5	2.78	39	13.5	66	22
5.0	2.82	46	14	66	18
8.0	2.86	50	15	66	17



## MECHANICAL PROPERTIES.—(Continued)

% Ni	$d_4^{20}$	BHN	UTS	$10^{-2} E$	El	RA
Al-Ni (R, A) (3, 8, 11, 13)						
1	2.72	34	11.8	66	32	52
2	2.75	38	12.5	66	30	50
3	2.77	44	14	66	27	45
4.5	2.80	44	15	66	25	42
6	2.82	45	15	66	22	35
8	2.85	47	15	66	16	24
10	2.91	53	16.5	66	8	12

% Ni	$d_4^{20}$	BHN	UTS	YP	El	RA
Al-Ni* (G <sub>m</sub> ) (3, 8, 11, 13)						
1	2.71	34	10	4	9	21
5	2.80	45	15	6.3	11	36
8	2.86					

Al-Ni-Cu* (G <sub>m</sub> ) 1% Cu (11)						
1	2.73	37	13.4	4.7	19	29
5	2.83	45	17	7	6	8

Al-Ni-Cu* (R, A) 2% Cu (11)						
1	2.77	53	16.5	6.3	30	57
5	2.82	60	19	7	25	36

% Si	$d_4^{20}$	BHN	UTS	PL	$10^{-2} E$	El
Al-Si (G <sub>s</sub> ) (1-3, 5-7, 9, 10, 12)						
5	2.65	40	12.6	2.4	63	5.5
8	2.63	44	12.6	2.4	63	5.5
13	2.60	50	14.5	3.2	60	2

Al-Si (G <sub>s</sub> M) (1-3, 5-7, 9, 10, 12)						
8	2.63	47	15.7	3	63	9
10	2.62	50	15.9	4.7	61	8
13	2.60	50	18.9	4.7	60	8

Al-Si (R, A) (1-3, 5-7, 9, 10, 12)			
% Si	BHN	UTS	El
1	28	9.5	45
1.5	30	9.9	43
2	30	10.3	41
5	35	11.8	35
10	40	12.6	27
15	47	14.2	17

\*  $10^{-2} E = 66$ .

## THERMAL PROPERTIES

## ANNEALING TEMPERATURES

250°C for Al-Mg (R, A).

275°C for Al-Fe, Al-Mn, Al-Ni (R, A), Al-Ni-Cu (R, A).

300° for Al-Mg (G<sub>s</sub> and G<sub>m</sub>), Al-Ni (G<sub>m</sub>), Al-Ni-Cu (G<sub>m</sub>), Al-Si.

## MOLD SHRINKAGE

## Al-Mg (1-3, 13, 14)

	Trt	% Mg				
		2	4	5	8	10
$-100 \frac{\Delta l}{l_0}$	G <sub>s</sub> .....	18.2	17.6	16.5	14.7	14.5
	G <sub>m</sub> .....	17.2	16.6	15.5	13.8	13.5

## Al-Mn (3, 13)

	Trt	% Mn				
		1.5				
$-100 \frac{\Delta l}{l_0}$	G <sub>s</sub> .....	21.0				
	G <sub>m</sub> .....	19.3				

Al-Ni (G<sub>m</sub>) (3, 8, 11, 13)

% Ni	1	5	8
$-100 \frac{\Delta l}{l_0}$	17.2	17.2	17.0

Al-Ni-Cu (G<sub>m</sub>) 1% Cu (11)

% Ni	1	5
$-100 \frac{\Delta l}{l_0}$	17.2	17.0

Al-Si (G<sub>s</sub>) (1-3, 5-7, 9, 10, 12)

% Si	3	5	8	13
$-100 \frac{\Delta l}{l_0}$	16.9	16.6	16.3	16.0

Al-Si (G<sub>s</sub>M) (1-3, 5-7, 9, 10, 12)

% Si	8	10	13
$-100 \frac{\Delta l}{l_0}$	16.3	16.0	16.0

Al-Si (G<sub>m</sub>) (1-3, 5-7, 9, 10, 12)

% Si	3	8	10
$-100 \frac{\Delta l}{l_0}$	15.2	14.4	13.3

Al-Si-Cu (G<sub>s</sub>) 2% Cu (4)

% Si	3	6	9
$-100 \frac{\Delta l}{l_0}$	17.1	15.8	16.0

## LITERATURE

(For a key to the periodicals see end of volume)

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# PROPERTIES OF MAGNESIUM AND OF ITS ALLOYS WITH MORE THAN 50% MAGNESIUM

ALBERT M. PORTEVIN

## Mg

Treatment	UTS	YP	El	RA	Lit.
F	23.6				(2)
DA	18-22	8-13	8-12 <sub>l</sub>		(21, 22)
G <sub>s</sub>	14.1	<i>v. also</i> under Mg-Al	8 <sub>s</sub>		(2)
	10.7		5		(18)
G <sub>m</sub>	12.4		4		(18)
R/83°			10 <sub>l</sub>	13	(16)

$UCS = 27.1 \text{ kg/mm}^2$  (3).

$ELC = 1.18 - 5.80$  (metal  $W_{H_2}$  600°/60°) (11).

$E = 4260 \text{ kg/mm}^2$  (28).

$G = 1700 \text{ kg/mm}^2$  (19).

$K = 2800 \text{ kg/mm}^2$  (19).

$ScH = 18$  for  $G_s$  (8).

$BHN_{\dagger} = 29.4_{BV}$  (25);  $28.6_{CX}$  (27);  $22-25_{C(V-Z)}$  (15).

$\log BHN_1 - \log BHN_2 = 0.0012 (t_2 - t_1)$  (14); *v. also* Fig. 1.

From experiments at B. P. of air at 10°, 15°, 50° and 70° C,

$\frac{E_{0^\circ \text{ abs.}}}{E_{0^\circ \text{ C}}} = 1.57$  (17).

For specific gravity, *v. p.* 456; for compressibility, *v. vol.* III; for viscosity, *v. vol.* III; for surface tension, *v. vol.* III.

## Mg-Ag

% Ag	3.4	9.8	36.0	41.5	Lit.
$BHN_{BV \dagger}$	40.1	48.5	104.7	136.2	(25)

## Mg-Al

Sand cast (8)

% Al	$100 \times d_{40}^{\circ}$	Hardness		Tensile properties			$10 \times UCS$	$10 \times BMR$
		$BHN_{CZ \dagger}$	$ScH$	$10 \times UTS$	$10 \times PL$	$10 \times El_a$		
0	174	60	28	100	14	54	175	225
2	174	45	19	169	35	101	250	301
4	175	50	22	184	44	84	289	336
5.8	176	53	22	197	56	74	293	360
6	176	53	24	197	56	74	293	360
8	177	60	28	178	63	40	299	344
10	179	66	32	161	77	20	314	324
12	180	71	34	148	91	10	315	304
15	182	75	38	117	112	5	319	311

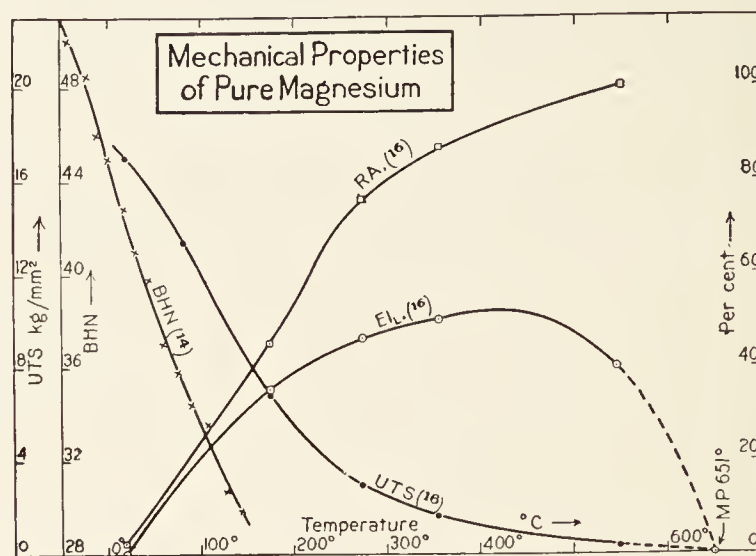
Al, 8 (Dowmetal A):  $UTS = 21.8$ ,  $UCS = 31.1$ ;  $BMR = 432$ ,  $E = 4260 \text{ kg/mm}^2$  (5).

Sand cast; annealed 2 hr at 800° (8).

% Al	Treatment	$10 \times UTS$	$10 \times YP$	$10 \times El$	$10 \times PL$	$10 \times RA$	Lit.
2.5	DA.....	231	133	150 <sub>l</sub>	{ Al, 0-5, sp. vol. = 0.575-0.0026 Al (23) }		(21, 22)
3	{ FA 450°....	231	105-148	95-150	{ 0.575-0.0026 Al (23) }		(26)
	{ G <sub>m</sub> .....	85	82	10	{ 0.575-0.0026 Al (23) }		(26)
4.5	DA.....	248	150	173 <sub>l</sub>	{ Al, 6-11, $E = 4400$ kg/mm <sup>2</sup> (1) }		(21, 22)
5	DA.....	254	142	180 <sub>l</sub>	{ Al, 6-11, $E = 4400$ kg/mm <sup>2</sup> (1) }		(21, 22)
6.12	{ D.....	295-309			88-129		(1)
	{ RA 300°....	290	262-270	75-80 <sub>l</sub>	28	46	(1)
	{ G <sub>hm</sub> .....	143-154	83-85	45-50 <sub>l</sub>	{ Al (QA) LCH (16) }		(18)
	{ G <sub>m</sub> .....	181		50	4	69.0-71.0	(18)
	{ G <sub>s</sub> .....	100		70	8	83.0-84.8	(26)
8	{ G <sub>m</sub> .....	235	133	5-10	15	91.0-91.8	(26)
	{ FA 400°/30.	200	150	20			(26)
11	DA.....	280	220	80 <sub>l</sub>			(20)
11.18	G <sub>hm</sub> .....	134-146	130-135	10 <sub>s</sub>	31	3.4	(1, 5)
15	G <sub>m</sub> .....	119	119	0			(26)
28	G <sub>m</sub> .....	55	55	0	Al, 7; $BHN_{CZ} = 50$		(21, 22, 26)

## Mg-Al-Cu

% Al	% Cu	Treat-ment	UTS	YP	El	Lit.	Treat-ment	UTS	Lit.
10.7	1	DA	30.5	20	8.5	(14)	D <sub>c</sub> 20 %	30	(21, 22)
8	9		28	20	5	(15)			



## Mg-Al-Cu-Cd, Etc., Dowmetals D, R and T (G<sub>s</sub>) (8)

% composition					Name	$100 \times d_{40}^{\circ}$	$BHN_{CZ \dagger}$	$ScH$	$10 \times UTS$	$10 \times PL$	$10 \times El_a$	$10 \times UCS$
Al	Cu	Cd	Zn	Mn								
8.3	2.0	1.0	0.5	0.2	D	184	58	29	155	98	20	299
8.0	1.0	1.0			R	181	54	23	165	67	45	302
2.0	3.8	2.0		0.2	T	184	45	24	145	98	37	239

## Mg-Al-Ni

% Al	% Ni	Trt	$10 \times UTS$	$10 \times YP$	$10 \times El$	Lit.
8.6	0.7	DA	295	165	130 <sub>l</sub>	(20)

## Mg-Cd

% Cd	Trt	$10 \times UTS$	$10 \times YP$	$10 \times PL$	$10 \times El$	$10 \times RA$	Lit.	% Cd	$BHN_{\dagger}$ (27)
1.1	F	222	177		50 <sub>s</sub>	69	(1)	16.1	31.9 <sub>CX</sub>
	R	180-183	176	91	7.5-10 <sub>s</sub>		(1)	19.6	34.9 <sub>CX</sub>
	D	152-181	176				(1)		
	G <sub>hm</sub>	70	44	19	35 <sub>s</sub>	31	(1)	23.7 <sub>†</sub>	{ 46 <sub>CZ</sub> § 13.5 <sub>CW</sub>
4	DA	206	118		75 <sub>l</sub>		(21, 22)	34.1	42.6 <sub>CX</sub>
5.5	DA	206	124		113 <sub>l</sub>		(21, 22)	45.1	51.9 <sub>CX</sub>
								53.7	64.9 <sub>CX</sub>

Cd, 0-6: sp. vol. = 0.575-0.0047 Cd (23).

Cd, 1:  $E = 4400 \text{ kg/mm}^2$  (1).

## Mg-Mn

Mn, 0-4; specific volume = 0.575-0.0043 Mn (23).

## Mg, 98.8; Si, 1.2 (DA)

$UTS = 29 \text{ kg/mm}^2$ ;  $YP = 22.2 \text{ kg/mm}^2$ ;  $El = 5\%$  (20).

## Mg-Sn (QA)

Sn, 4:  $LCH = 57.0-60.0$ ; Sn, 8:  $LCH = 68.0-70.0$ ; Sn, 15:  $LCH = 79.0-79.5$  (16).



## Mg-Cu

% Cu	Treatment	$100 \times d_4^{20}$	BHN	ScH	$10 \times UTS$	$10 \times YP$	$10 \times PL$	$10 \times EL$	$100 \times RA$	$10 \times UCS$	Lit.
3.02	RA 300°				171-189	162		10 <sub>s</sub>			(1)
4	G <sub>s</sub>	179	43	25	109		35	15 <sub>a</sub>		211	(8)
	QA	LCH = 62.0-64.5				Cu 4 (G <sub>s</sub> ) is Dowmetal S					(16)
4.5	DA				209	146		45 <sub>l</sub>			(21, 22)
8	QA	LCH = 77.0-80.3								Cu, 3-14, E = 4400	(16)
9	DA	Cu 0-13, sp. vol. = 0.575-				234	200	30 <sub>l</sub>		kg/mm <sup>2</sup>	(21, 22)
12.7	DA					246	219	20 <sub>l</sub>			(21, 22)
13.64	G <sub>hm</sub>	0.0052 Cu (2 <sup>3</sup> )				120	116	31	7.5 <sub>s</sub>	36	(1)

## Mg-Zn

% Zn	Trt	UTS	YP	$10 \times EL$	Lit.
2.5	DA	23.0	11	170 <sub>l</sub>	(21, 22)
3.8	DA	23.7	12	145 <sub>l</sub>	(21, 22)
5	G <sub>s</sub>	18		74 <sub>s</sub>	(8)
8	G <sub>m</sub>	17		30	(18)
	G <sub>s</sub>	14.3		40	(18)

% Zn	Trt	BHN†	ScH	Lit.
5	DA	45 <sub>CZ</sub>		(21, 22)
	D <sub>d</sub>	67 <sub>CY</sub>		(8)
		47 <sub>CY</sub>		(8)
	G <sub>s</sub>	41 <sub>CZ</sub>		(8)
			23	(8)

% Zn	LCH for (QA) (16)
4	62.0-65.8
8	77.0-78.7
15	103-104

Zn, 5-15, is "electron;" Zn, 0-5: sp. vol. = 0.575-0.0043 Zn (23); Zn, 4: E = 4400 kg/mm<sup>2</sup> (1).

## Mg-Zn-Al (21, 22)

Compo- sition	Treatment	UTS	El <sub>h</sub>	Zn	Al	Treatment	BHNCz†	UTS	YP	PL	El <sub>s</sub>	RA
Zn, 3; Al, 0.5	D <sub>c</sub> 30 %	32	3.5	3	2	DA	45	25.3		7	11.0	13.4
	D <sub>c</sub> 10 %	27	8	1.8	5	DA	50	to		to	to	to
	DA	23	17	5	2	DA	50	27.7		10	12.5	16.3

Mg-Zn, 4.3; Al, 1.6;  
Cu, 0.74 (D) "Elec-  
tron" Metal (1)

## Mg-Zn-Cu, "Electron" Metal

% com- position		$100 \times d_4^{20}$	BHN <sup>†</sup>	Tension				Compres- sion¶		IS Charpy kg-m/cm <sup>2</sup> (13)	Lit.
Zn	Cu			$10 \times UTS$	$10 \times YP$	El <sub>s</sub>	RA	$10 \times UCS$	$10 \times YP$		
4.24	0.42	179	51-48**	283	119	19		352	95		(4)
4.62	.20	178	51-50**	253	189	19		363	47		(4)
4.37	.62	179	63-59**	289	189	13		377	132		(4)
"Electron" 181-183				232	13	15	16			0-1.0	(6, 7)

\* Heated in hydrogen.

† Subscripts to Brinell hardness Nos.:

Subscripts	Ball diam., mm	Subscripts	Load, kg	Subscripts	Load, kg
A	1	U	10	X	200
B	5.564	V	50	Y	250
C	10	W	116	Z	500

‡ Tested at 300°C (8).

§ G, Q<sub>w</sub>.

|| Round bars, 7-6 mm diam.

¶ Cylinders, 7.85 mm × 7.85 mm diam.

\*\* Exterior and transverse section, respectively.

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(For a key to the periodicals see end of volume)

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## ZINC AND ITS ALLOYS CONTAINING MORE THAN 50% ZN

## C. BENEDICKS

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TABLE 1.—MECHANICAL PROPERTIES

## Zn

Trt	R				Tested in liquid air				G	Single crystal
					A 100°	A 200°	A 260°	A 300°		
UTS	12-26	17	15-30	27	15*	14†	6-16*	5*	3	2.2-2.5
Lit.	(40)	(41)	(38)	(36, 37)				(48)	(35)	

\*A 30 m. †A 5 m.

YP = 9 ± 3 kg/mm<sup>2</sup> (40).

Extrusion Pressure = 75 kg/mm<sup>2</sup> (29).

PL and EL: None defined (6, 11, 13); cf. however (16).

EL = 5-30 % on 150 mm } (6, 40).

RA = 5-60 %

For UTS and El vs. t, °C; v. Fig. 1; v. also (38, 45).

TABLE 1.—MECHANICAL PROPERTIES.—(Continued)

(45)	A at: $t, ^\circ\text{C} \dots$									
	70	100	150	200	250	300	350	380		
	UTS	17.6	15.7	15.7	15.4	17.0	12.4	10.2	5.5	5.2
$El_a$										
30 41 42 38 13 11 9 2 3										
<hr/>										
Obs. $BHN$		Red. $BHN$		Ball diam.		Load, kg		Lit.		
$H$		$H_r$		mm						
46		46		10		500		(12)		
31*		35		10		50-100		(29)		
40		40		10?		500		(31)		
61†		52		5		500		(7)		

\* Rate of indentation = 0.25 mm/min. † Rolled.

$H_r = BHN$  reduced to 10 mm, 500 kg by formula:  $H_r = \Pi \frac{x + P_0 \sqrt[5]{\frac{\rho}{P}}}{x + P} \sqrt[5]{\frac{\rho}{P}}$  (8), where  $\rho$  = radius of ball,  $P$  = load (kg),  $x = 3700$  for  $140 < P < 500$ . Reduction to 10 mm, 3000 kg not performed as being uncertain. Concerning reduction, *v. also* (3).

Trt	G	Wk <sub>0</sub>	A 80°	A 100°	A 125°	A 250°
$BHN^*$	38	64	64	51	43	43
Temp., $^\circ\text{C}$	-50	-25	0	25	50	75 100 125
$BHN^\dagger$	88	78	69	61	54	47 41 36

\* 1 mm ball; 5 kg load (39). † Faired values (24).

$LCH = 62 \pm 2$  (31).

$ScH = 10$  (31); 11 (42); 10.8 (9); *v. also* Fig. 2.

For some typical hysteresis diagrams, *v. Fig. 3*.

For: specific gravity, *v. p.* 456; compressibility, *v. vol.* III; viscosity, *v. vol.* III; surface tension, *v. vol.* III.

Zn-Al; *v. also* (20, 21, 25, 26, 43)

Zn, 94; Al, 6 (A, $t, ^\circ\text{C}$ )			Trt		$G_s$ (44)			$G_m$ (44)		
$t, ^\circ\text{C}$	UTS	$El_a$	% Al		UTS	YP	$El_a$	UTS	YP	$El_a$
70	23.2	66	10		24.3	16.7	10.3	22.3	17.8	1.9
100	27.5	60	20		29.1	26.6	6.7	29.3	22.5	1.5
150	22.3	54	25		29.0	12.7	10.1	31.7	21.3	2.2
200	22.2	49	30		27.9	16.9	4.3	28.3	13.5	2.7
250	25.0	24	35		26.5	11.8	3.5	26.3	16.0	0.6
300	28.3	21	40		28.3	16.6	2.6	26.7	9.4	1.6
350	23.8	43	45		28.3	15.0	2.7	24.4	10.7	1.1
380	22.7	43	50		29.2	20.3	4.1	34.0	8.0	1.1
380	22.3	42								

(45)

Al, 0-50: For  $IS$  of ( $G_s$ ) or ( $G_m$ ), *v. Fig. 5*.  
For  $BHN$  of ( $Q$ ) or ( $A$ ), *v. Fig. 4*; *v. also* Figs. 6 and 7.

$LCH$ of Zn-Al, $Q$ , or $A$ 360°/2-3 h (30).		Trt			
		% Al	0.5	1	2 4
$Q \dots \dots \dots$			61-64	82-85	86-91 74-80
$A \ 360^\circ \dots \dots \dots$			64-66	78-83	88-90 74-76

Zn-Al-Cu; *v. also* (20, 21, 25, 26, 43)

Hot rolled (45)									Chill cast (45)			
%Cu		1			3			9		1	3	9
% Al		UTS	El <sub>a</sub>	BHN	UTS	El <sub>a</sub>	BHN	UTS	BHN	UTS	UTS	UTS
0		30.7	39	66	31.5	31	83	47.3	99	8.7	11.5	20.7
2		33.2	37	103						18.9		
4		34.1	28	104	33.0	51	115	56.0	129	22.0	24.7	28.0
6		38.2	50		36.5	57	107	45.0	134	22.3	28.4	26.6
8		33.2	38	110	35.2	50	123			27.8	28.3	
15		37.3	47	103	34.0	44	129	43.4	146	30.2	30.8	34.1

Cold rolled					Zn, 97; Al, 2; Cu, 1 (annealed at t°C)						
% Al	% Cu	UTS	El <sub>a</sub>	t, °C	UTS	El <sub>a</sub>	t, °C	UTS	El <sub>a</sub>		
2	1	30.8	39		29.0	45		250	28.0	6	
4	1	35.7	32	70	27.5	40		300	25.3		
4	3	31.3	17	100	29.2	35		350	27.6	8	
6	1	35.3	4	150	27.3	39		380	22.8	5	
(45)					200	29.3	15	(45)			

TABLE 1.—MECHANICAL PROPERTIES.—(Continued)

For  $UTS$ ,  $YPC$ ,  $BHN$  of Al, 0-11; Cu, 0-10; *v. Figs. 6 and 7*.  
**Zn-Cd**  
Values of  $LCH$  (30); *v. also* Figs. 5, 6, p. 549, 550; (17) and (49)

% Cd		0.25	0.5	1	2	4	8
Trt							
$Q \dots \dots \dots$		63-65	74-75	89-91	94-95	85-89	78-79
$A \ 260^\circ/2-3 \text{ h} \dots \dots \dots$		65-73	79-85	94-100	98-103	96-98	85-89

For  $USS$ , *v. Fig. 8*, p. 550.

Zn-Cu; *v. also* (20, 21, 25, 26, 43)

% Cu				Zn, 97; Cu, 3 (A, $t, ^\circ\text{C}$ )		Trt		G	A
				$t, ^\circ\text{C}$	UTS	$El_a$		$BHN$	$BHN$
0	3.4	0.0	40						
1.75	4.3	22.5	60		28.8	36	0	35	35
4.1	13.9	22.5	75	70	28.6	34	3.5	64	56
6.7	18.2	23.7	82	100	27.4	35	5.0	74	61
8	21.0	23.2	85	150	27.2	38	8.7	57	65
10.5	22.7	30.0	100	200	29.2	35	14.3	64	73
<hr/>									
(48)									
% Cu*					UTS	$El_a$			
0		9.1	0	250	21.5		19.4	102	102
1		24.8	54	300	21.7	37	25.0	189	143
3		34.0	13	350	22.5	40	44.7	188	174
				380	21.7	33	49.5	93	93
				(45)		(26)			

\* Cold rolled alloys (45)

Zn, 51.97; Cu, 48.03 (15)

Temp., $^\circ\text{C} \dots \dots$	16	300	450	500	600	700	760	820
$IHN^* \dots \dots \dots$	166	174	169	132	62	38	26	22

\* For method, *v. (14)*.

LUDWIK CONE HARDNESS OF Zn-Mg, Zn-Sb, AND Zn-Sn (30)

Trt		Q		A		Trt		Q		A		$t, ^\circ\text{C}$
Wt.%				350°/2-3h		Wt.%				$t^\circ/2-3 \text{ h}$		
Mg 0.25		87-90		76-79		Sb 1		47-50		51-53		390
0.5		92-99		87-97		2		51-52.5		54-55		
1		101-103		102-103		Sn 4		42-43		40-42		150
2		111-116		128-129		8		40-41		38-39		

TABLE 2.—ELASTIC PROPERTIES OF ZN

$E$	10 480	10 300	9 600	8 000-13 000	8 090			
$G$	3 800	3 880				3 100	1 600	2 990
Lit.	(28)	(52)	(40)	(18)	(41)	(50)	(47)	(23)
<hr/>								
Temp., $^\circ\text{C} \dots \dots$	18	21	48	52	63	67	82	97
$G \dots \dots \dots$	3110	3100	2980	2890	2810	2790	2620	2440 (50)*

$\frac{1}{E} \frac{dE}{dt} = 0.0035 \text{ per } ^\circ\text{C}$  (53) (very uncertain extrapolation).†

\* *v. also* (23, 27, 51).  
† *v. also* (34).

ELASTIC CONSTANTS OF A SINGLE CRYSTAL (19)

$\varphi$  = angle between axis of tension and hexagonal axis.

$\varphi$	3.6	4.7	22	23	30	37	48	56	81	81	88
$10^{-1}E \dots \dots \dots$	359	356		472	539	675	878	1162	1230	1267	1178
$10^{-1}G \dots \dots \dots$	374	377	350	328	333	324	289	315	464	473	479

$K$  = bulk modulus = 10 100 kg/mm<sup>2</sup> (52).  
 $\lambda = 0.3$  (52);  $\lambda = 0.33$  (eale. from  $G$  and  $E$ ) (47).



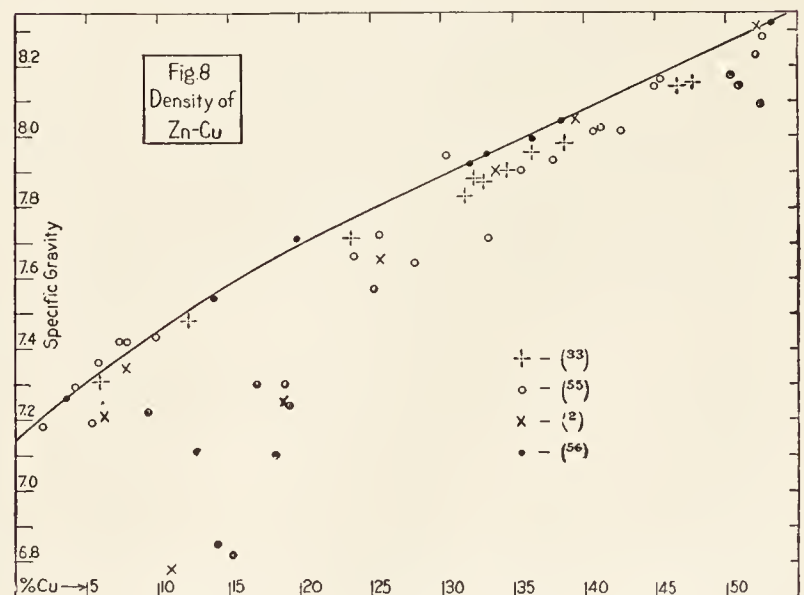
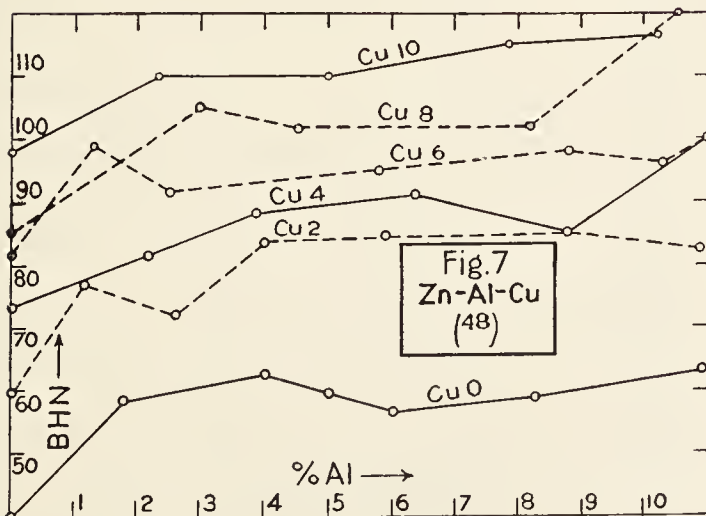
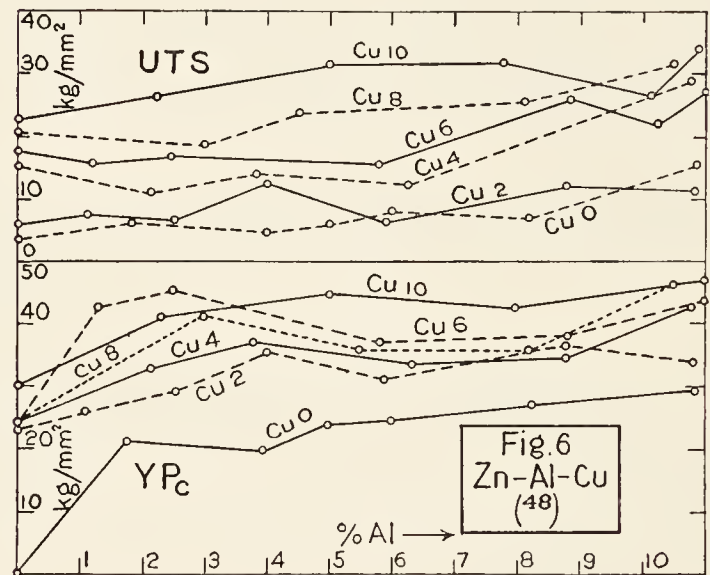
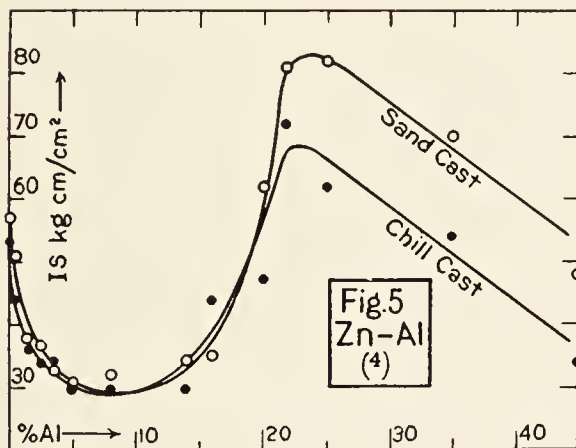
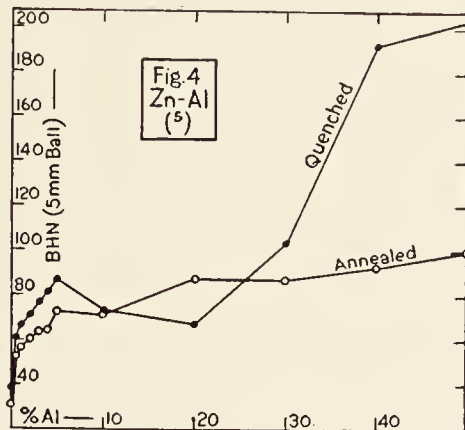
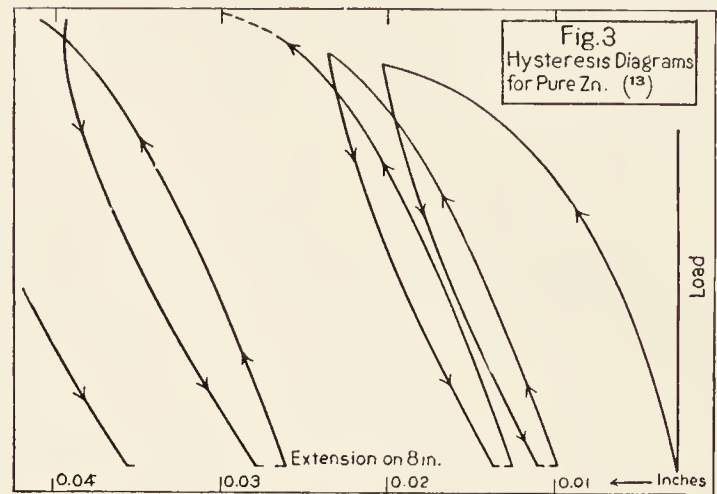
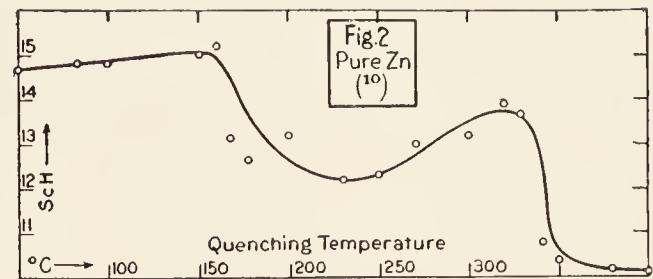
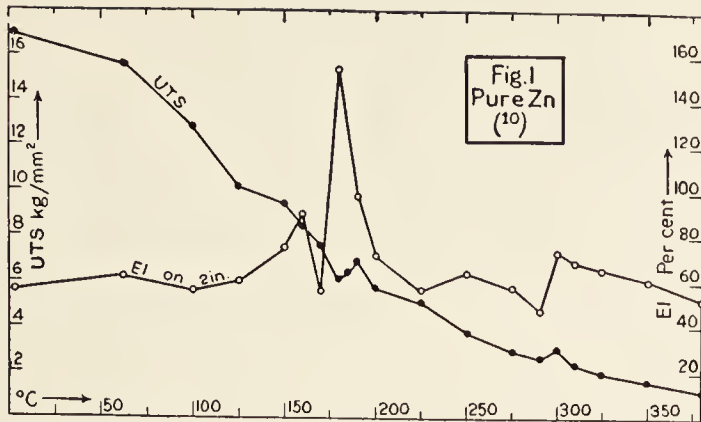


TABLE 3.—COMPRESSIBILITY OF ZN ALLOYS\* (32)

Wt. %	Temp., °C	Range, atm.	10 <sup>6</sup> $\chi$ per atm.
Al 5	19.0	1-1050	1.9
25	15.4	1-1050	2.3
50	18.0	1-1050	1.8
Cd 10	21.5	1-1050	1.7
40	22.5	1-1050	2.8
Cu 10	6.0	1-1050	1.8
30	25.2	1-1050	1.5
50	20.5	1-1050	1.9
Pb 20	9	1-2100	1.6
	104	1-2100	3.3

\* For compressibility of pure Zn, v. vol. III.

TABLE 4.—SPECIFIC GRAVITY OF ZN ALLOYS

For specific gravity of pure Zn, v. p. 456

Zn-Al (44)				Zn-Cu					
Chill cast		Sand cast		v. Fig. 8. The low values obtained by many investigators in the range 5-30% Cu are due to shrinking cracks and porosity. Values of (55) are checked by X-ray analysis.					
% Al	$d_4^{20}$	% Al	$d_4^{20}$						
9.59	6.120	9.69	6.182	Zn, 65; Sb, 35* (46)					
19.40	5.380	20.03	5.458						
25.37	5.008	24.98	5.043						
30.78	4.768	30.58	4.707						
34.65	4.383	35.20	4.487						
40.80	4.123	40.37	4.290	t, °C					
44.85	4.103	45.02	3.992						
50.30	3.920	50.38	3.906						
				d	6.56	6.20	6.14	6.07	6.01

\* M. P. = 510°C.

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## CADMIUM AND ITS ALLOYS WITH AG, AS, AU, BI, CU, HG, MG, PB, SN, TL, AND ZN

C. H. M. JENKINS

Cd (v. also Fig. 1)

Treatment	UTS	El	RA	Lit.
G <sub>m</sub> , 1 in. diam.....	8.5	52	80	(7.3)
R <sub>c</sub> , V 12 mo.....	7	95	>90	(7.3)
R <sub>c</sub> , V 12 mo, 300°/1 d.....	6.1	64	85	(7.3)

$$\left. \begin{aligned} 10^{-3} E &= 7.070 \\ 10^{-3} G &= 2.450 \end{aligned} \right\} (17).$$

$$E_{0^\circ\text{C}}/E_{0^\circ\text{abs.}} = 2.50 \text{ (by damping of wires) (13).}$$

$$BHN = \begin{cases} 21-24 \text{ (as cast)} \\ 21 \text{ (worked, aged 1 mo)} \end{cases} \text{ 10 mm ball, 500 kg.}$$

Changes in hardness occur at atmospheric temperatures. Present values of BHN of worked material are unsatisfactory (2, 6).

$\log BHN_1 - \log BHN_2 = 0.00295 (t_2 - t_1)$ ; between  $-45^\circ\text{C}$  and  $+142^\circ\text{C}$  (10 mm ball, 500 kg) (7).

For effect of temperature on properties, v. Fig. 1.

For: density, v. p. 456; compressibility v. vol. III; viscosity, v. vol. III; surface tension v. vol. III.

## Cd-Ag

Compound Cd-Ag: BHN = 74 (10 mm ball, 200 kg) (12).

## Cd-As

For density v. Fig. 7.

## Cd-Au

For hardness v. Fig. 2.

## Cd-Bi

For hardness v. Fig. 3.

## Cd-Cu

Cast material (7.1)

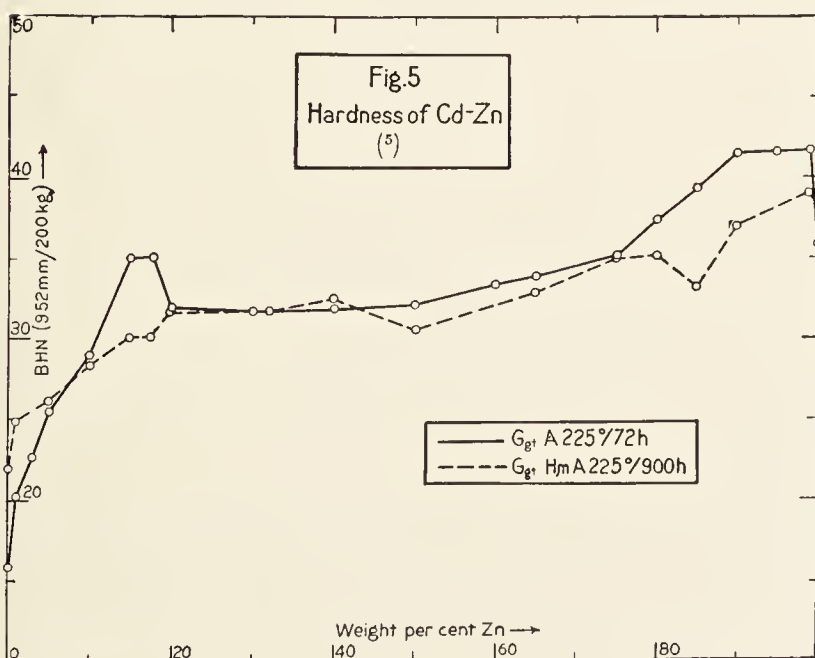
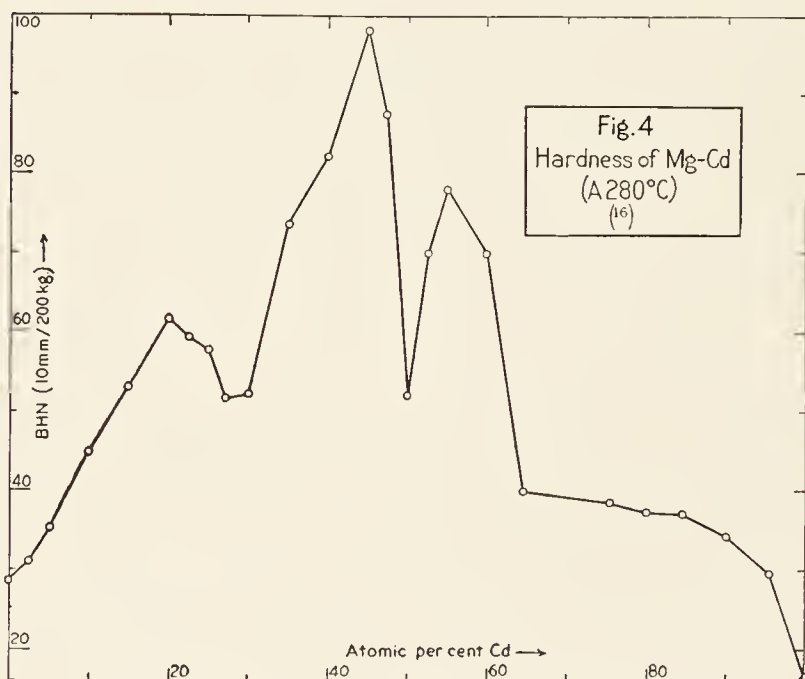
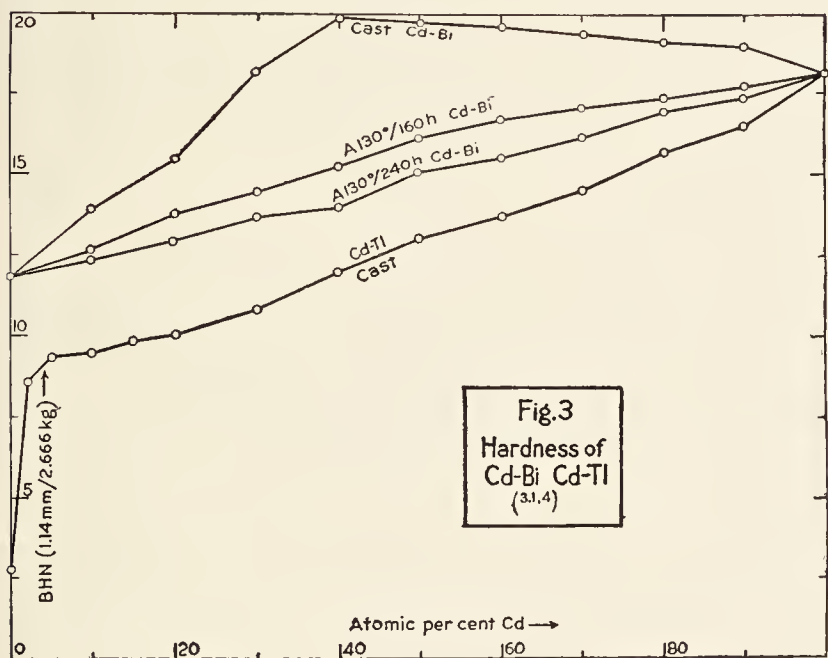
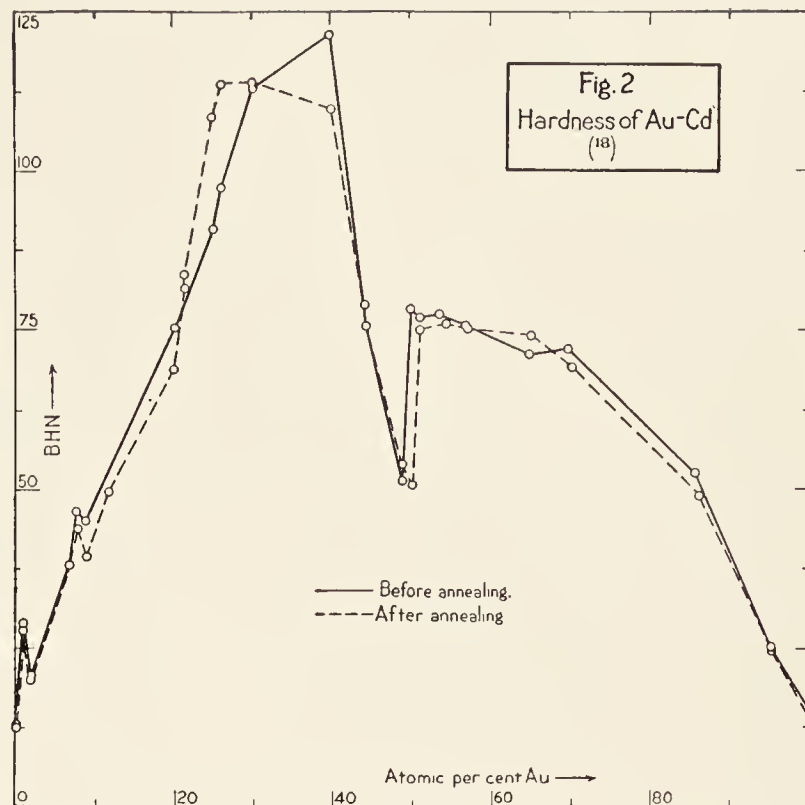
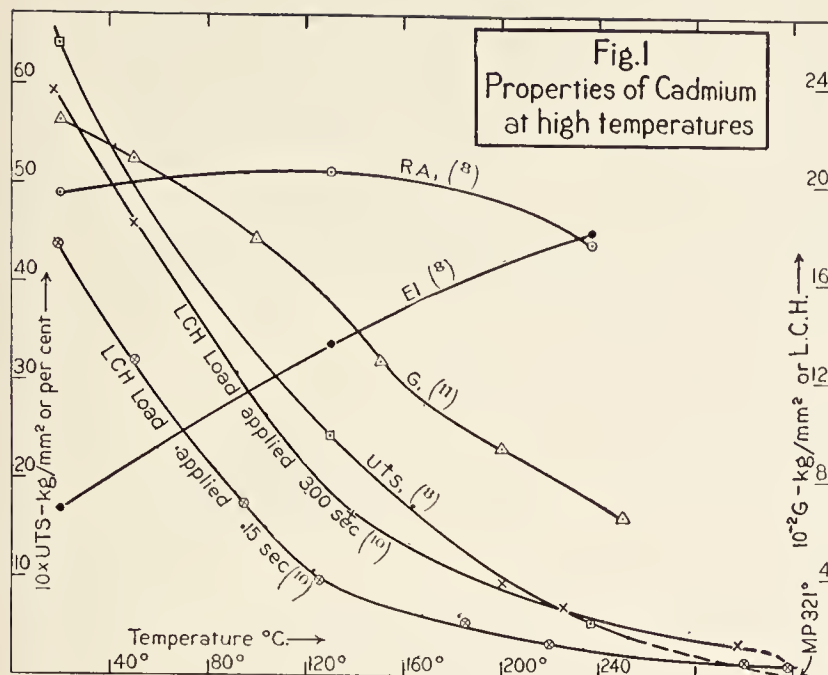
% Cu	UTS	El	RA
Nil	8.75	65	80
Nil	8.35	38	58
0.52	11.4	48	76
0.54	12.2	44	66
1.00	13.7	19	51
1.03	13.25	42	76
1.95	14.6	21	3
2.00	15.2	18	13
2.86	15.45	3	2
2.90	14.9	4	3
4.83	15.5	0	0

Rolled material, aged 3 mo at room temperature (8)

Nil	8.8	58	>90
Nil	9.0	59	>90
0.54	10.4	50	>90
0.54	10.5	90	>90
1.00	11.8	44	>90
1.00	11.8	67	>90
2.00	13.7	50	68
2.00	13.1	38	64
2.86	13.85	21	10

Continued on p. 549





Cd-Cu.—(Continued)

Annealed rolled material (annealed for 6 wk at 250°C. Reduction by rolling, 70%) (7.1)

% Cu	UTS	El	RA
Nil	6.9	54	86
Nil	6.85	61	87
0.52	11.35	50	74
0.52	11.2	58	80
1.03	12.75	38	68
1.03	12.9	50	70
1.95	14.2	36	42
1.95	13.7	37	42
2.90	14.5	24	15
2.90	14.0	25	25

Continued on p. 551

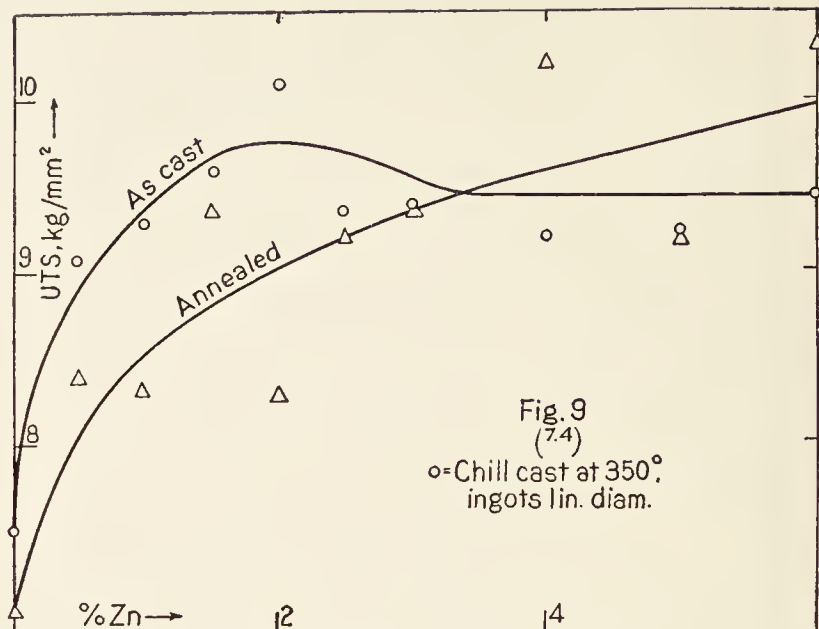
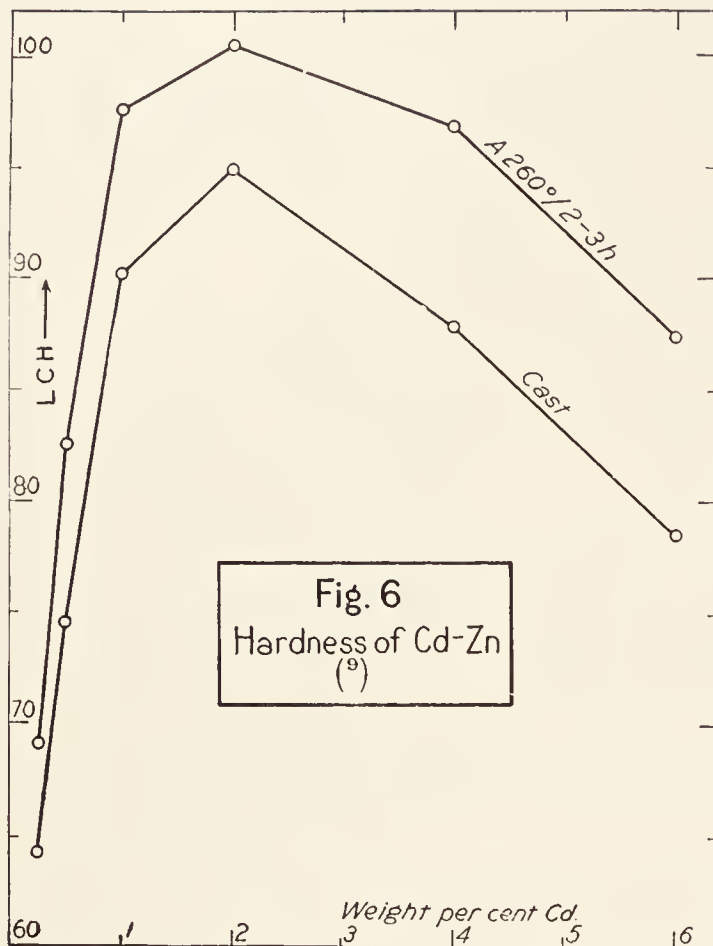
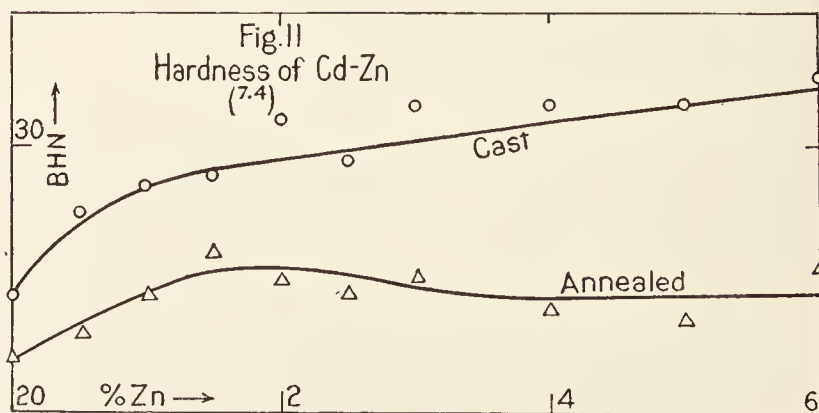
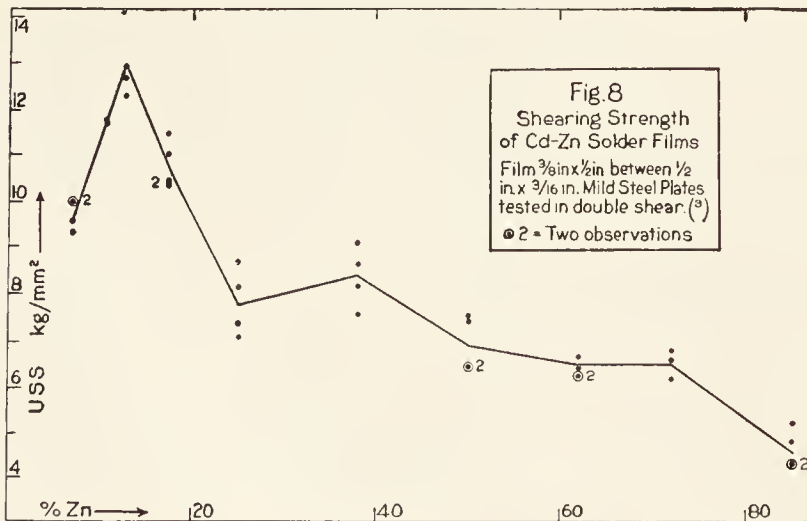
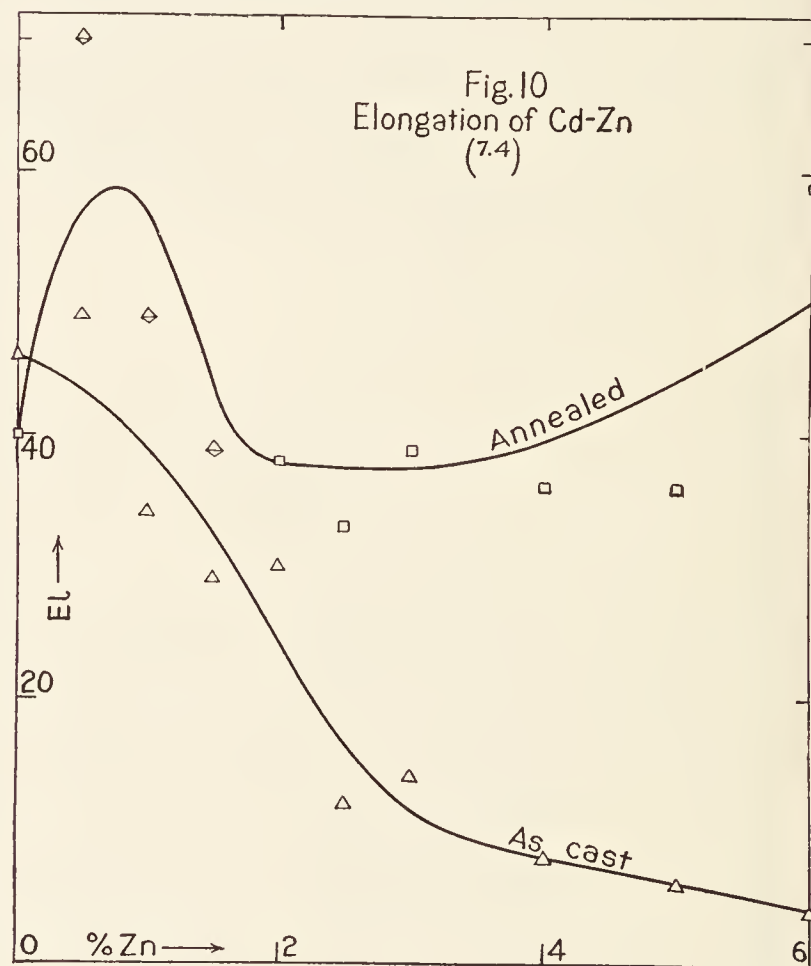
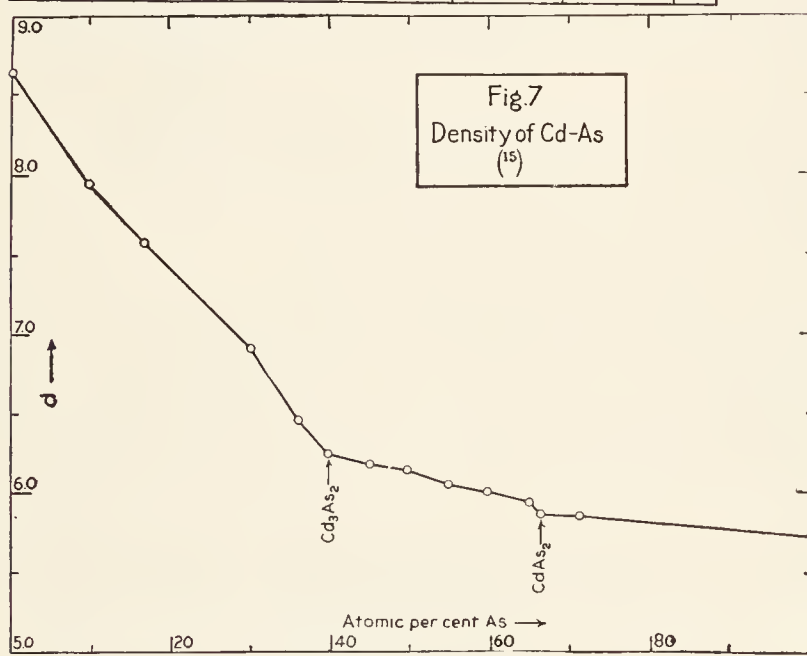


Fig. 9.—Tensile strength of Cd-Zn.





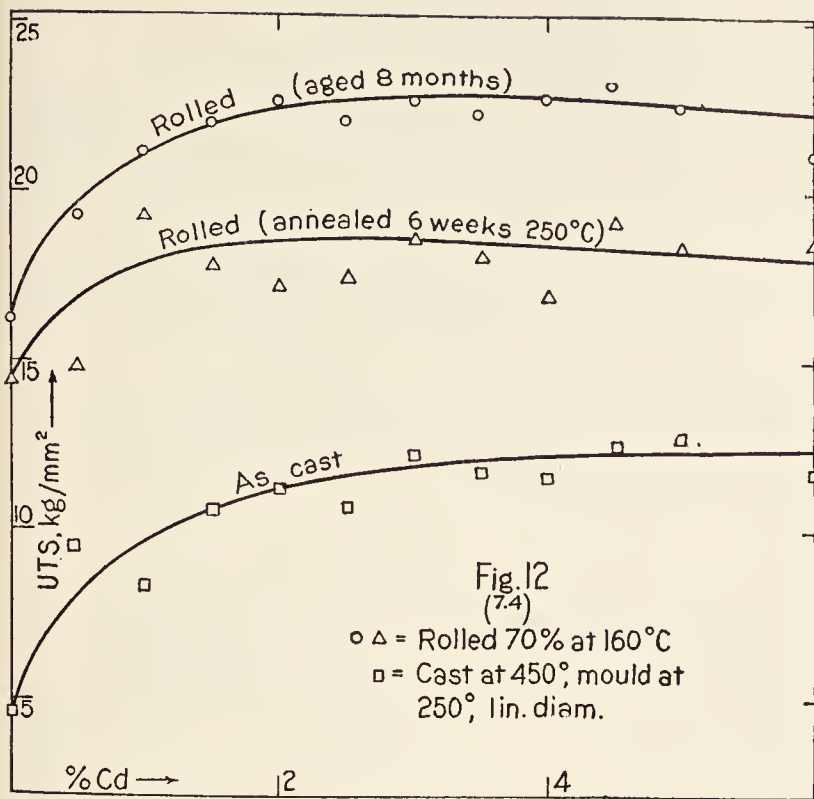
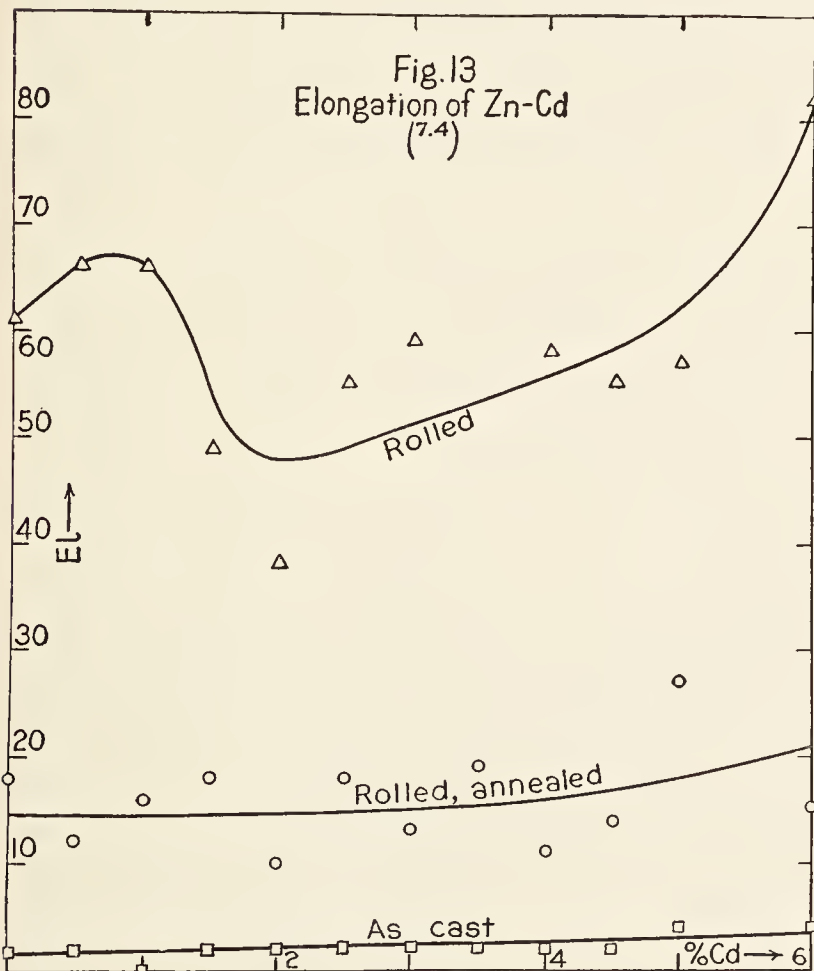
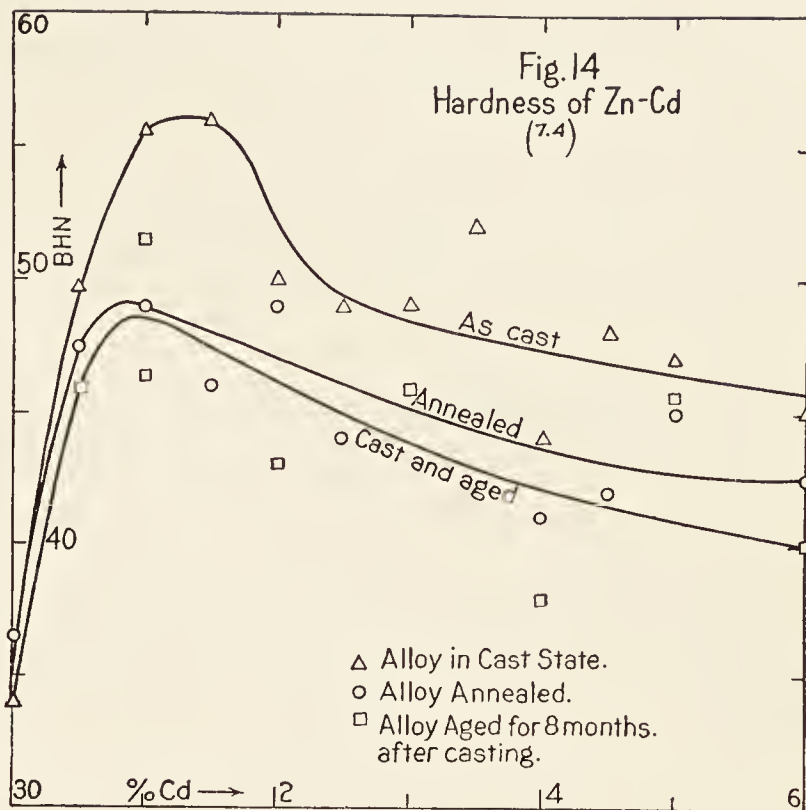


Fig. 12.—Tensile strength of Cd-Zn.



Cd-Cu.—(Continued)

% Cu	BHN*		
	Max.	Min.	Mean
Cast material			
0	25	24	24.5
0.52	36	32	34
1.03	39	36	38
1.95	42	38	41
2.90	46	44	45
4.83	57	51	54
Material annealed for 6 wk at 250°C			
0	26	25	25.5
0.54	33	32	33
1.00	36	34	35
2.00	39	38	38.5
2.86	44	40	41.5
4.81	52	49	50

\* 10 mm ball, 500 kg applied 3 min.

Cd-Hg

For density *v.* Fig. 10, p. 590.

Cd-Mg

Compound Cd-Mg: BHN = 52 (12) (10 mm ball, 200 kg);  
*v.* also Fig. 4.

Cd-Pb-Sn\*

% Pb	% Cd	% Sn	$d_4^{20}$	UTS	El	Lit.
90	10	0	11.09	3.51	37.5	(1)
85	10	5	10.67			(1)
80	10	10	10.35	4.03	52.3	(1)
75	10	15	10.26	4.14	41.7	(1)

\* Solders.

Cd-Tl

For hardness *v.* Fig. 3.

Cd-Zn (7.2); *v. also* Figs. 5, 6, 8-14.

% Cd	UTS	El	RA	Treatment
82.6	15.75	30	35	As cast*
82.6	11.6	68	90	A 250°/6 w†
94.0	9.45	5	5	As cast*
94.0	11.4	60	90	A 250°/6 w†

\* Casting conditions: Poured at 270°C into cold cast iron mold 1 in. diam.

† Material reduced 70 % by cold rolling and annealed for 6 wk at 250°C.

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(For a key to the periodicals see end of the volume)

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# MECHANICAL PROPERTIES OF COPPER AND ITS ALLOYS WITH Ag, As, Bi, Cd, Fe, Mn, O, P, Sb, AND Si

D. HANSON

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## TENSILE (COMPRESSIVE) AND ELASTIC PROPERTIES

Cu (*v. also* Figs. 1-4 and pp. 558-560)

Tensile properties of electrolytic Cu (RA 700°/30) (11)

Wt. % composition	<i>t</i> , °C	10 <sup>2</sup> UTS	El <sub>a</sub>	RA
O <sub>2</sub> , 0.015; Si, Tr.....	Room	2277	58	72.7
	250	1631	50.8	65.1
O <sub>2</sub> , 0.016; Si, Tr.....	Room	2273	53.6	76.8
	250	1566	54	69.4

Compression of Cu cylinder 54.07 mm × 27.73 mm diam. (25)

*P* = Load, kg; *A* = cross-section area, mm<sup>2</sup>; *A*<sub>0</sub> = original cross section area, mm<sup>2</sup>.

<i>P/A</i> <sub>0</sub> .....	16.8	25.3	33.7	42.1	50.7	59.0	67.4	75.8	84.2
-100Δ <i>l/l</i> <sub>0</sub> .....	0.94	1.32	8.41	20.6	30.6	39.1	46.2	51.6	55.9
<i>P/A</i> .....	16.7	24.9	30.8	33.4	35.0	35.9	36.2	36.6	37.1

USS = UTS, same variations (24).

Electrolytic, annealed, 10<sup>-2</sup>*E* = 123 - 131 (8, 20, 23).*E* = *E*<sub>0</sub> (1 + α*t*), where α = -3.59 × 10<sup>-4</sup> (6, 26).Pure, 10<sup>-2</sup> *G* = 43.2 (16).

λ = 0.31 - 0.34 (1, 8, 20).

Composition, hundredths %	UTS	YP	El	RA
As   O   Ag				

Cu-As (R<sub>h</sub> to 1/8 in. diam., Q) (17)

24			23.6	14.2	27*	<i>v. also</i> Figs. 1 and 4
53			25.2	13.4	29*	
75			24.9	12.6	21*	
94			24.4	12.6	25*	
137			25.7	12.6	28*	
180			24.4	16.1	20*	

Cu-As-Ag-O (R<sub>cA</sub> DR/30 Q) (13)

30	5.6	4.2	22.7		35 <sub>b</sub>	<i>v. also</i> Figs. 1, 3, 4,
42	6.3	9.4	22.9		35 <sub>b</sub>	
45	5.8	17.5	24.0		43 <sub>b</sub>	
42	4.8	29	24.1		43 <sub>b</sub>	

Composition, hundredths %			<i>UTS</i>	<i>YP</i>	<i>El</i>	<i>RA</i>
As	O	Ag				
Cu-As-O (4)						
26	12	0.7	24.4	14.8	40	79
94	15	0.8	25.4	13.6	54	70
194	20	0.5	26.0	9.8	62	80

Composition, hundredths %			UTS	El
As	O			
Cu-As-Bi-O (R <sub>cA</sub> DR/30 Q) (1 <sup>3</sup> )				
42	5.5	Bi 5.1	23.8	42 <sub>b</sub>
40	6.8	7.3	22.8	40 <sub>b</sub>
39	8.4	9.7	23.2	33 <sub>b</sub>
47	7.3	12.4	23.3	35 <sub>b</sub>

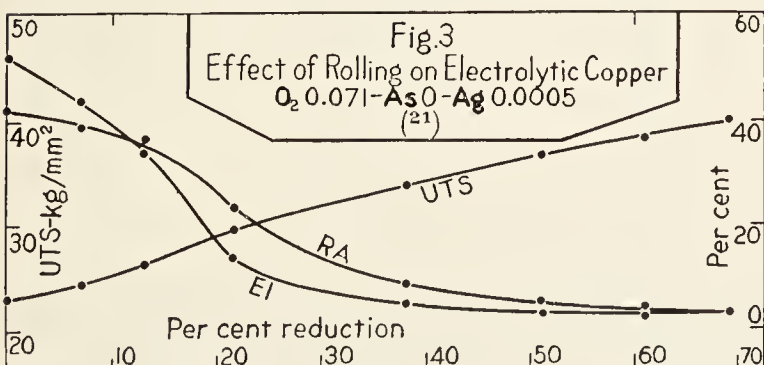
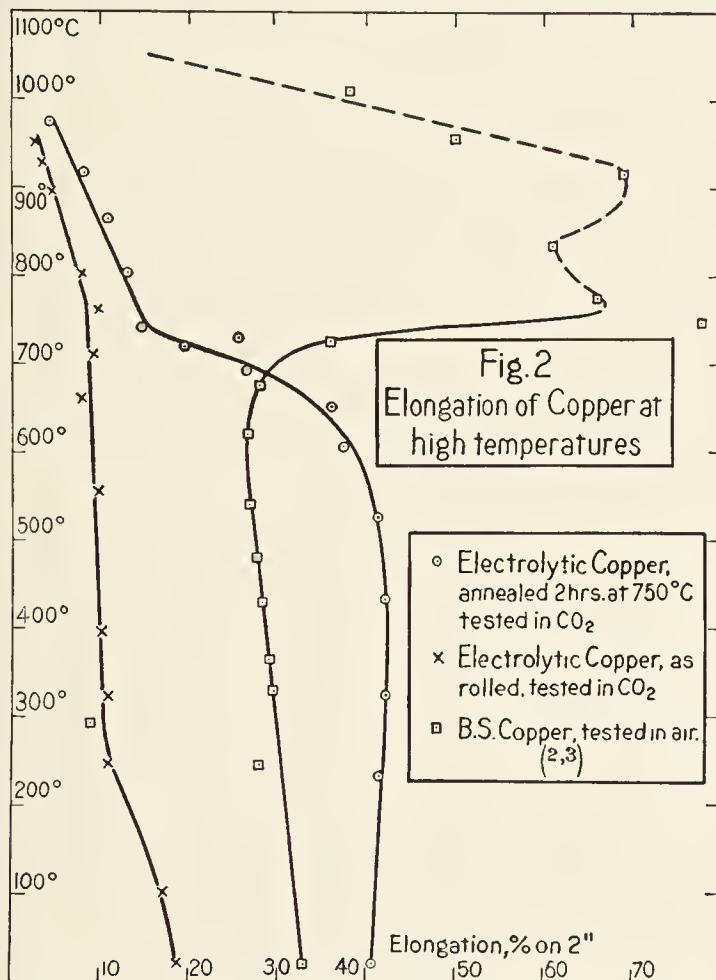
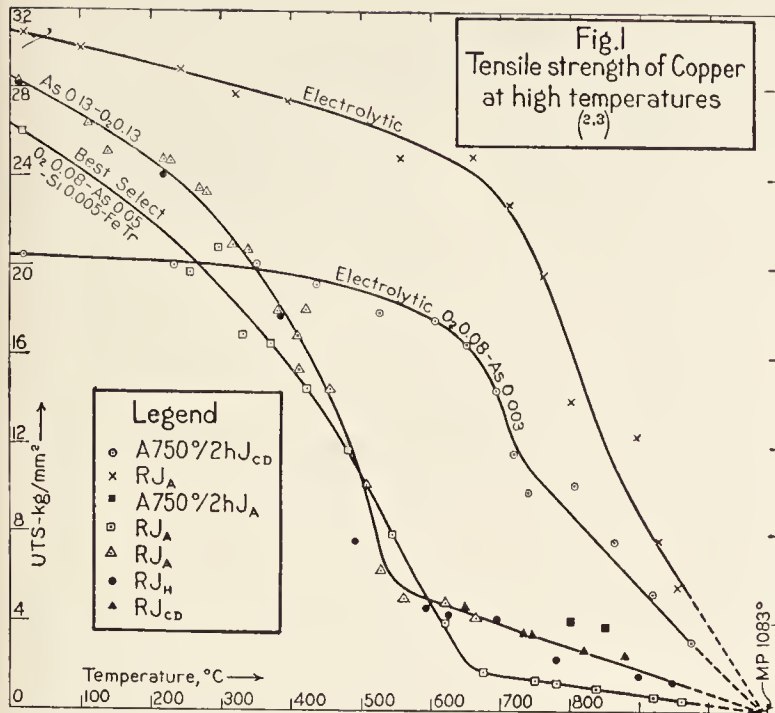
Cu-As-Sb (A 800°/15) (14)				
36	6.5	Sb 20	23.5	48 <sub>b</sub>

Composition, hundredths %	UTS	YP	El	CS*
Cd   Fe   O				
Cu-As-Si-Fe (15)				
34	Fe 3.5	Si 2	24.4	43
36	6	20	24.6	50
35	7	15	25.1	40
39	13	22	25.7	37
38	13	36	25.5	41
35	24	80	28.8	37
37	5	0.0	25.5	46
69	43	0.0	27.0	48

\* Gage length = 1 in.

Composition, hundredths %			<i>UTS</i>	<i>YP</i>	<i>El</i>	CS*
Cd	Fe	O				
Cu-Cd (G) (5)						
50			17.0	2.4	14	17.0
100			20.5	2.4	13	20.4
200			22.1	1.81	13	22.1
300			22.1	2.44	11	22.1
400			21.3	2.44	10	21.6
700			15.8	2.5	5	16.5
1100			11.0	3.0	5	11.6
1400			7.1	3.2		7.2



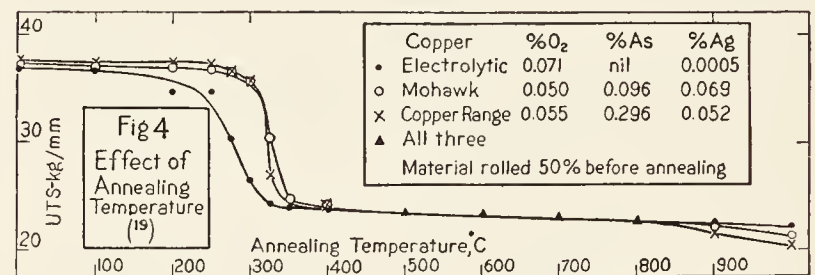


Composition hundredths %			UTS		El	RA
	Fe	O				
Cu-Fe (RA 700°/30) (10)						
v. also Fig. 5	6	1.4	$\left\{ \begin{array}{l} 22.8 \\ 16.5 \end{array} \right.$	$\left\{ \begin{array}{l} (A) \\ (B) \end{array} \right.$	$\left\{ \begin{array}{l} 57_s \\ 51.7_s \end{array} \right.$	$\left\{ \begin{array}{l} 73 \\ 63 \end{array} \right.$
	20	0.3	22.4	(A)	60 <sub>s</sub>	75
	40	0.4	$\left\{ \begin{array}{l} 23.6 \\ 16.9 \end{array} \right.$	$\left\{ \begin{array}{l} (A) \\ (B) \end{array} \right.$	$\left\{ \begin{array}{l} 60_s \\ 50.8_s \end{array} \right.$	$\left\{ \begin{array}{l} 80 \\ 68 \end{array} \right.$
	73	0.8	$\left\{ \begin{array}{l} 26.5 \\ 18.1 \end{array} \right.$	$\left\{ \begin{array}{l} (A) \\ (B) \end{array} \right.$	$\left\{ \begin{array}{l} 51.7_s \\ 51.4_s \end{array} \right.$	$\left\{ \begin{array}{l} 80 \\ 83 \end{array} \right.$
	96	0.5	$\left\{ \begin{array}{l} 25.2 \\ 19.1 \end{array} \right.$	$\left\{ \begin{array}{l} (A) \\ (B) \end{array} \right.$	$\left\{ \begin{array}{l} 45_s \\ 42.5_s \end{array} \right.$	$\left\{ \begin{array}{l} 82 \\ 88 \end{array} \right.$
	138	0.4	$\left\{ \begin{array}{l} 30.4 \\ 23.2 \end{array} \right.$	$\left\{ \begin{array}{l} (A) \\ (B) \end{array} \right.$	$\left\{ \begin{array}{l} 29.6_s \\ 20_s \end{array} \right.$	$\left\{ \begin{array}{l} 79 \\ 81 \end{array} \right.$
	180	0.7	$\left\{ \begin{array}{l} 31.2 \\ 25.7 \end{array} \right.$	$\left\{ \begin{array}{l} (A) \\ (B) \end{array} \right.$	$\left\{ \begin{array}{l} 29.0_s \\ 24.6_s \end{array} \right.$	$\left\{ \begin{array}{l} 79 \\ 82 \end{array} \right.$
	209	0.8	$\left\{ \begin{array}{l} 34.8 \\ 27.3 \end{array} \right.$	$\left\{ \begin{array}{l} (A) \\ (B) \end{array} \right.$	$\left\{ \begin{array}{l} 33.7_s \\ 27_s \end{array} \right.$	$\left\{ \begin{array}{l} 79 \\ 80 \end{array} \right.$

\*  $\Delta l = -\frac{1}{2}l_0$ .

(A) Tested at room temp.

(B) Tested at 250°C.



Composition, hundredths %		Trt	UTS	El
Mn	P			
Cu-Mn (RA 500° C <sub>s</sub> or Q) (21)				
4	1.2	{ C <sub>s</sub> ..... Q.....	32.6 34.2	45.5 45
7	1.5	{ C <sub>s</sub> ..... Q.....	33.2 34.4	45 44.5
12	1.4	{ C <sub>s</sub> ..... Q.....	33.9 34.4	44.5 44
19	2.1	{ C <sub>s</sub> ..... Q.....	33.6 34.7	44 44
29	2.2	{ C <sub>s</sub> ..... Q.....	34.5 34.8	44.5 44
40	2.0	{ C <sub>s</sub> ..... Q.....	34.7 35.5	44.5 44
61	2.4	{ C <sub>s</sub> ..... Q.....	34.8 35.8	44.5 43
98	2.1	{ C <sub>s</sub> ..... Q.....	36.7 37.8	44.5 43
134	2.3	{ C <sub>s</sub> ..... Q.....	38.6 40.0	42.5 40.5
149	2.6	{ C <sub>s</sub> ..... Q.....	39.1 40.8	40.5 40

## Cu-O (RA 700°/30) (11)

% O	$t, ^\circ\text{C}$	UTS	$El_s$	RA
0.04	20.....	22.57	50	71.4
	250.....	15.86	58	69.5
0.06	20.....	22.7	56	70.2
	250.....	16.27	50.8	65.1
0.09	20.....	23.2	52.5 <sub>a</sub>	64.7
	250.....	17.05	56.4	67.8
0.17	20.....	24.20	49.2	56.4
	250.....	17.2	52	66
0.28	20.....	24.53	38	42.5
	250.....	17.0	48.8	58
0.36	20.....	26.2	34	38
	250.....	17.8	47.2	62.8

## Cu-P (21)

% P	(R)		(RA 500° C <sub>s</sub> )		(RA 500° Q)	
	UTS	El	UTS	El	UTS	El
0.014	36.1	4.3	23.0	46.5	24.6	45
.042	38.6	3.9	23.0	46	25.1	44
.092	39.5	3.0	23.5	45	25.1	43
.173	39.6	2.8	24.3	42	25.7	41.5
.399	42.7	3.0	25.4	41	26.2	40
.563	46.4	2.3	26.9	40	28.8	40
1.062	53.4	2.0	28.7	40	31.8	38

## HARDNESS OF CU AND ITS ALLOYS WITH AG, CD, FE, MN, O, P AND SI

% composition		BHN	% composition		BHN
Cu (electrolytic)			Cu-Mn-P†.—(Continued)		
(G) (11)		28–30*	RA 500° C <sub>s</sub>		
(Dp) (11)		58–66	Mn 0.04		74
Cu-Ag (22)			.19		74
A 750–770°/24 h			.29		77
Ag 4.2		63	.40		77
5.5		72	.61		81
Cu-Cd (G) (5)			.98		84
Cd 0.5		55	1.34		84
1.0		65	1.49		88
2–14		66	Cu-O (G) (11)		
Cu-Fe (G) (10)			O 0.015		30
Fe 0.06		28	.036		33
.2		28.2	.06		34
.4		35	.08		36
.73		44	.17		43
.96		45	.28		53
1.38		45	.36		57
1.80		49.5	Cu-P (21) R		
2.09		49	P 0.014		96
Cu-Mn (A) (22)			.042		101
Mn 7.2		71.5	.092		112
15.3		108	.173		118
31.1		140	.399		130
Cu-Mn-P† (21)			.563		141
RA 500° Q			1.06		160
Mn 0.04		77	RA 500° C <sub>s</sub>		
.29		84	P 0.014		63
.40		77	.042		65
.61		81	.092		68
1.34		88	.173		70
			.399		74
			.563		77
			1.06		84

## HARDNESS OF CU AND ITS ALLOYS WITH AG, CD, FE, MN, O, P AND SI.—(Continued)

% composition		BHN	% composition		BHN
RA 500° Q			Cu-Si (22)		
P 0.014		74	A 800–900°/1 h		
.042		74	Si 1.7		59
.092		74	2.2		71.5
.173		74	2.6		73
.399		77	2.7		82
.563		77	3.8		120
1.06		96			

Scleroscope hardness of pure Cu (A), 6–8; (R<sub>c</sub> 66%), 22–24 (4, 7).

\* 10 mm ball/500 kg load; others 5 mm/500 kg.

† Contains 0.12–0.2 % P.

## SPECIFIC GRAVITY\* OF COPPER AND ITS ALLOYS WITH FE, MN, P AND O

Annealed high conductivity Cu,  $d_4^{20} = 8.86$ – $8.92$  (variable with oxygen content and soundness of ingot) (6, 9, 11, 12). For density of pure Cu, *v. p.* 456.

## Cu-Fe (11)

% Fe	$d_4^{20}$	
	R	RA†
0.06	8.92	8.90
.2	8.92	8.92
.4	8.92	8.92
.73	8.92	8.91
.96	8.92	8.91
1.38	8.91	8.91
1.8	8.90	8.91
2.09	8.90	8.90

Cu-Mn-P } (21)  
Cu-P

% Mn	% P	$d_4^{20}$
0.04	0.012	8.905
.19	.021	8.903
.98	.021	8.860
1.49	0.026	8.820
	0.04	8.945
	.173	8.938
	.399	8.903
	1.062	8.758

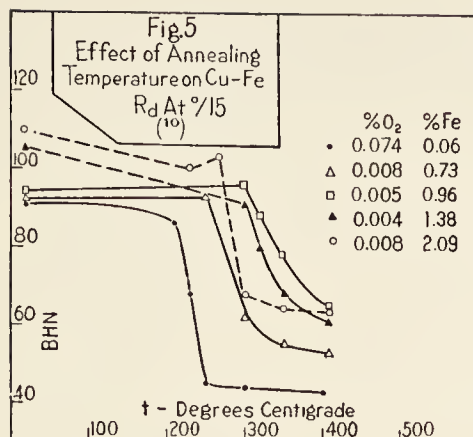
## Cu-O (11)

% O	$d_4^{20}$	
	R	RA†
0.015	8.917	8.912
.016	8.92	8.91
.04	8.907	8.905
.06	8.910	8.901
.09	8.884	8.882
.17	8.825	8.842
.28	8.8	8.8
.36	8.75	8.76

\* All specific gravity values for alloys refer to rolled or worked material. Densities of castings mainly unreliable owing to irregular unsoundness.

† R, A 700°/30.





## LITERATURE

(For a key to the periodicals see end of volume)

- (1) Amagat, *34*, 108: 1199; 89. (2) Bengough, *47*, 7: 123; 12. (3) Bengough and Hanson, *47*, 12: 56; 14. (4) Bengough and Hill, *47*, 3: 34; 10. (5) Budgen, *Cadmium and Its Alloys*. London, Griffin and Co., 1924. (6) Bureau of Standards, *365*, 73: 32, 38; 18. (7) Caesar and Gerner, *40*, 10: 203; 16. (8) Carrington, *3*, 41: 206; 21. (9) Dellinger, *459*, 58: 889; 11. (10) Hanson and Ford, *47*, 32: 335; 24. (11) Hanson, Marryat and Ford, *47*, 30: 197; 23. (12) International Electrotechnical Commission, *Publication No. 28*: 4; 14. (13) Johnson, *47*, 4: 163; 10. (14) Johnson, *47*, 7: 240; 12. (15) Johnson, *47*, 10: 275; 13. (16) Koch and Dannecker, *8*, 47: 197; 15. (17) Lewis, *135*, 83: 3; 01. (18) Macnaughton, *140*, 109: 409; 24. (19) Mathewson and Thalheimer, *80*, 55: 446; 16. (20) Morrow, *3*, 6: 417; 03. (21) Munker, *192*, 9: 185; 12. (22) Norbury, *47*, 29: 423; 23. (23) Searle, *3*, 49: 193; 00. (24) Thurston, *Materials of Engineering*, Part III. New York, Wiley, 1910. (25) Unwin, *Testing of Materials of Construction*. London, Longmans, Green and Co., 1910. (26) Wassmuth, *75*, 115, II A: 223; 06.

## PROPERTIES OF BRASSES AND OF Pb, Sb, Sn AND THEIR ALLOYS

O. F. HUDSON

For specific gravities of the pure metals *v. p.* 456; for compressibilities, *v. vol.* III; for viscosities, *v. vol.* III; for surface tension, *v. vol.* III.

## Cu-Zn, SIMPLE BRASSES\*

% Cu		$d_{18}^{\dagger}$	BHN	ScH	UTS	YP	PL	El <sub>a</sub>	RA	UCS	IS <sub>2</sub> <sup>‡</sup> (Izod)	Shr.
	Lit	(1)	(12, 13)	(13)	(5, 6, 13-17)	(13)	(13)	(6, 13-17)	(13-15)	(5)	(4)	(18)
90	G <sub>s</sub> .....	8.75	45	12	22			25		21	5.5	2.1
	R <sub>d</sub> .....		120	41	39			5				
	R <sub>s</sub> .....		43	11	25			45				
80	G <sub>s</sub> .....	8.62	45	12	25			30	30	27	6.9	1.87
	R <sub>d</sub> .....		145	50	47			10	30			
	R <sub>s</sub> .....		45	12	28			50	85			
70	G <sub>s</sub> .....	8.50	45	12	28	16		35	35	42	6.2	1.79
	R <sub>d</sub> .....		145	50	47	47	24	15	50			
	R <sub>s</sub> .....		45	12	28	9	6	70	75			
66	G <sub>s</sub> .....		48	13	28			30	30		7.6	2.29
	R <sub>d</sub> .....		145	50	50			15	50			
	R <sub>s</sub> .....		43	16	31			60	70			
65	As rolled, EL <sub>S</sub> = 20; annealed, EL <sub>S</sub> = 6 (from torsion tests) (13)											
60	G <sub>s</sub> .....	8.40	70	20	36	20		20	25	53	6.2	2.34
	R <sub>d</sub> .....		150	55	47	39	19	35	45			
	R <sub>s</sub> .....		60	16	39	17	6	55	60			
56	G <sub>s</sub> .....		80		47			20				2.37
	G <sub>m</sub> .....		95									
52	G <sub>s</sub> .....		90		31			10			6.2	2.50
	G <sub>m</sub> .....		85									
50	G <sub>s</sub> .....		95		16			5		77		2.50
	G <sub>m</sub> .....	8.30	90									

Elastic properties of brass, composition not stated:  $10^{-2}E = 79-92$  (G<sub>s</sub>); = 92 (R<sub>d</sub>); = 100 (R<sub>s</sub>) (5);  $10^{-2}G = 36$ ;  $\lambda = 0.327$  (22).

\* Mechanical properties of brasses vary widely with condition. Data given are typical of alloys in the indicated conditions.

† For chill castings.

‡ Standard 120 ft. lb. specimens with 11, 23, and 46 ft. lb. tups.

§ USS = 24 (G) (9); EL<sub>S</sub> = 8.5 (R<sub>s</sub>) (13).

## EFFECT OF ROLLING ON HARDNESS OF BRASS

Cu, 66.65; Pb, 0.3; Fe, 0.08 (24)

$\gamma^*$ .....	2	4	8	12	15	25	50
ScH.....	9.7	12.7	15.2	17.3	21.5	27.4	38.2

\*  $\gamma$  = Per cent reduction in rolling.

EFFECT OF ANNEALING ON  $\alpha$ -BRASS

% composition	$t_A, ^\circ\text{C}^*$	YP	UTS	El <sub>a</sub>	RA
Cu, 71; Zn, 28.53; Pb, 0.25; Fe, 0.20; Sn, 0.02 ( $\frac{1}{2}$ in. diam.)† (15)	(20)	33.9	39.4	35	65
	285	32.9	40.3	35	66
	350	28.8	39.7	38.5	53
	400	25.5	38.7	46	53.5
	500	9.1	32.9	67.5	74.5
	725	6.8	29.1	80	75
Cu, 69.4; Zn, 30.44; Fe, 0.15; Pb, 0.005; Sn, trace ( $\frac{1}{2}$ in. diam.)† (15)	920	5.8	28.7	78	63
	(20)	49.6	49.9	19.0	65
	320	43.1	51.8	19.5	65.5
	405	17.8	39.5	55	75.5
	500	19.5	36.5		72
	570	15.1	36.9	60	77
	630	10.2	33.1	65	75
	660	10.1	32.3	76.5	80
	702	8.0	31.5	76	77
	765	6.5	31.2	79	70
	808	5.4	29.0	81	75
	900	5.2	27.9	83.5	70

% composition	$t_A, ^\circ\text{C}^*$	ScH	UTS	El <sub>a</sub>	RA
Cu, 66.65; Zn, 23.97; Pb, 0.3; Fe, 0.08 (cross-section 0.5 in. $\times$ 0.1 in.)‡ (24)	(20)	34.5	62.5	6	34.8
	350	19.5	40.6	38	54.4
	450	16.3	37.5	48	60
	550	12.8	34.5	58	61.4
	650	9.5	31.6	68	58.4
	750	7.5	29.7	67	56.7

$\alpha$ -Brass (24), composition not stated. R<sub>d</sub>, 40%; UTS = 53.9; El = 11.1. A 200°/30: UTS = 55.1; El = 10.0.

\* Annealed 30 min. at  $t_A, ^\circ\text{C}$ .

† R<sub>d</sub>.

‡ 50% reduction.

## ANNEALING TEMPERATURES FOR SIMPLE BRASSES

For 70/30 Brass: A 650  $\pm$  10° gives complete softening and moderate grain size (13).

For 60/40 Brass: A 650° for final treatment but for subsequent hot working, reheat up to ca. 800° (13).

For 70/30 or 60/40 Brass: To remove dangerous internal stress, A 250° (28, 29).

EFFECT OF ANNEALING ON  $BHN$  OF  $R_d$   $\alpha$ -BRASS (2)Cu, 68.48; Zn, 31.47; Pb, 0.02; Fe, 0.03, annealed 30 min at  $t_A$ , °C

$t_A$ , °C	$\gamma^*$	20.2	36.6	50.9	59.1
20		110	142	158	163
200		109	148	169	172
250		106	143	166	171
275		104	140	155	154
300		103	137	130	124
325		102	106	93.3	93.3
350		102	100	91.2	91.9
375		88.3	88.8	86.4	88.6
400		82.6	74.6	79.6	83.8
425		75.2	71.2	76.5	79.0
450		75.0	70.5	74.1	77.4
500		70.4	66.2	69.1	69.1
550		65.9	61.3	62.0	62.0
600		61.7	55.4	56.8	57.2
650		55.8	51.5	52.1	52.4
700		50.6	48.9	49.7	49.2
750		46.0	45.9	46.4	46.4
800		43.9	43.1	43.1	44.1
850		41.3	41.1	42.0	41.7

\*  $\gamma$  = Per cent reduction in rolling.

## PHYSICAL PROPERTIES OF VARIOUS BRASSES

Composition and treatment	$BHN$	$UTS$	$YP$	$EL_a$	$RA$	Lit.
Cu-Zn-Al, Al-brasses						
Cu, 70.5; Zn, 26.4; Al, 3.1.....		33.0		50		(5)
Cu, 69.79; Zn, 26.67; Al, 3.54 {	G.....	104	39.0	21.3	26.0	27.6 (32)
	F.....	143	58.2	36.8	34.0	41.9
Cu, 69.42; Zn, 24.68; Al, 5.90 {	G.....	185	59.8	44.1	3.0	1.5 (32)
	F.....	193	66.6	51.2	6.0	8.4
Cu, 69.13; Zn, 26.32; Al, 4.55 {	G.....	134	50.2	27.7	8.0	11.7 (32)
	F.....	143	60.8	31.9	17.0	20.0
Cu, 62.9; Zn, 33.3; Al, 3.8.....		56.2				(5)
Cu, 59.85; Zn, 37.13; Al, 3.02 {	G.....	159	66.1	35.1	18.5	21.5 (32)
	F.....	154	63.4	28.5	24.5	30.6
Cu, 59.48; Zn, 39.52; Al, 1.00 {	G.....	114	50.4	23.3	30	33.5 (32)
	F.....	104	49.3	17.5	41.0	44.6
Cu, 58.26; Zn, 38.56; Al, 2.18 {	G.....	138	57.3	25.2	16.0	21.5 (32)
	F.....	143	58.2	18.4	27.0	33.5
Cu, 57; Zn, 42; Al, 1.....	G.....		40.0		50	(5)
Cu, 55; Zn, 41; Al, 4.....			60.0		16.5	(5)
Cu-Zn-Fe, Fe-brasses						
Cu, 60; Zn, 38.2; Fe, 1.8.....	G.....		40.3	"Aich's metal"		(5)
Cu, 59.37; Zn, 39.68; Fe, 0.95 {	G.....	90	42.2	14.8	44	44.6 (32)
	F.....	107	45.3	21.9	44	63.7
Cu, 59.12; Zn, 38.36; Fe, 2.52 {	G.....	92	41.7	15.7	46	49.7 (32)
	F.....	110	44.1	24.9	39	54.6
Cu, 59.04; Zn, 30.95; Fe, 1.56 {	G.....	85	42.2	15.7	33	30.6 (32)
	F.....	98	42.6	21.4	43	59.3
Cu, 55.04; Zn, 42.36; Fe, 0.83; Sn, 0.83; "Sterro metal" {	G.....		42.5			(20)
	F.....		53.5			
	D <sub>c</sub> .....		59.8			
	$EL_C$		$10^{-4}E$	$10^{-4}G$		
Cu, 73.85; Zn, 25.90; Fe, 0.25 {	$H_{1/2}$ .....	18.9	1.186	0.387		(21)
	$H_{1/2}$ A 610°	7.1	1.191	0.408		
Cu, 67.08; Zn, 32.45; Fe, 0.44 {	D <sub>d</sub> .....	23.9	1.068	0.381		(21)
	D <sub>d</sub> A 610°	8.7	1.128	0.410		

## Cu-Zn-Mn, Mn-brass

Composition and treatment	$BHN$	$UTS$	$YP$	$EL_a$	$RA$	Lit.
Cu, 59.6; Zn, 38.0; Mn, 2.1.....	G.....		41	14	50	(13)
Cu, 57.6; Zn, 41.0; Mn, 1.16.....	G.....		42.5	16	50	(12)
Cu, 58.95; Zn, 39.92; Mn, 1.01; Fe, 0.24; Si, 0.05 {	G.....	80	39.4	15.9	51	49.7 (32)
	F.....		41.6	15.9	47	57

## PHYSICAL PROPERTIES OF VARIOUS BRASSES.—(Continued)

Composition and treatment	$BHN$	$UTS$	$YP$	$EL_a$	$RA$	Lit.
Cu, 58.42; Zn, 39.25; Mn, 2.0; Fe, 0.25; Si, 0.05 {	G.....	90	40.8	14.3	45	52.7 (32)
	F.....					
Cu, 58.42; Zn, 39.8; Mn, 1.48; Fe, 0.25; Si, 0.05 {	G.....	90	40.9	14.0	49	61.5 (32)
	F.....					

## Cu-Zn-Mn-Al, etc., High tensile brasses

Cu, 59.45; Zn, 35.85; Mn, 3.49; Al, 0.98; Fe, 0.22; P, 0.01 {	G.....	114	50	28	25	25 (32)
	F.....	134	55	33	36	47
Cu, 59.45; Zn, 36.6; Mn, 1.97; Al, 1.56; Fe, 0.40; P, 0.02.....	G.....	138	57	27	22	20 (32)
	F.....	148	58	27	28	30
Cu, 58.6; Zn, 38.5; Al, 1.5; Mn, 0.5; V, 0.03 {	D <sub>c</sub> .....		57.3	35.6	12	14 (20)
Cu, 58.15; Zn, 35.18; Mn, 4.10; Al, 2.24; Fe, 0.25; P, 0.08 {	G.....	165	63	38	14	15 (32)
	F.....	159	68	39	18	21
Cu, 57.23; Zn, 37.9; Al, 2.59; Mn, 2.08; Fe, 0.20 {	G.....	165	65	30	18	20 (32)
	F.....	159	66	31.5	24	25
Cu, 55.02; Zn, 41.9; Mn, 2.04; Fe, 0.75; Sn, 0.15; Al, 0.09.....		143	21	53.5	16	(13)

## Cu-Zn-Sn-(Fe), Sn-brasses

Cu, 70; Zn, 29; Sn, 1; "Admiralty condenser tube brass"	Mechanical properties substantially those of 70/30 brass					(13)	
Cu, 62; Zn, 37; Sn, 1; "Naval brass"	$\left\{ \begin{array}{l} G \\ R_d \\ R_s \end{array} \right.$	$\begin{array}{ccccc} 39 & 19 & 15 & 25 \\ 19^* & 50 & 39 & 20 & 30 \\ 8^* & 44 & 19 & 35 & 40 \end{array}$	(13)				
Cu, 60; Zn, 40; Sn, 0.7-1.1.....		$E = 10\ 500-13\ 400\ \text{kg/mm}^2$	(27)				
Cu, 59.95; Zn, 39.38; Sn, 0.47; Fe, 0.20	$\left\{ \begin{array}{l} G \\ F \end{array} \right.$	$\begin{array}{ccccc} 87 & 41 & 17 & 44 & 42 \\ 107 & 46 & 25 & 38 & 60 \end{array}$	(32)				
Cu, 59.17; Zn, 37.63; Sn, 2.98; Fe, 0.22..	G	136	33.4	26.0	1.5	3.2	(32)
Cu, 58.9; Zn, 40.1; Sn, 1.0.....	$\left\{ \begin{array}{l} G \\ F \end{array} \right.$	$\begin{array}{ccccc} 98 & 42.5 & 16 & 32 & 34 \\ 107 & 45.5 & 22 & 38 & 45 \end{array}$	(32)				
Cu, 58.82; Zn, 38.76; Sn, 2.11; Fe, 0.31..	G	114	41	19	13	15	(32)
Cu, 58.7; Zn, 39.6; Sn, 10; Fe, 0.34; Pb, 0.4; "Durana"			40.8	18.0	32	36	(16)
		$E = 7\ 430\ \text{kg/mm}^2$					

\* These values are for  $PL$ .

## PB

Treatment	$UTS$	Lit.	$BHN$	$10^{-3}E$	$10^{-3}G$	$\lambda$	Lit.
Cast.....	1.25	(23)	4.2				(7)
Rolled.....	2.1	(19)		1.5-1.7	0.55	0.43	(5)
Annealed.....	1.8	(19)		1.80			(35)
Drawn wire {	Soft	1.70	(22)	1.73			(35)
	Hard	2.20	(22)				
Pr, A 100°.....	1.7*	(5)	3.8				(7)

 $ScH = 2$  (ordinary hammer);  $ScH = 3$  (magnifier hammer) (31).For  $CS = 1.5\ \text{kg/mm}^2$ ,  $\Delta l = -32\% l_0$  } (7).  
 $EL_C = 0.07\ \text{kg/mm}^2$ .\*  $EL_a = 67\%$ .

## PB-Ba-Ca

(Ba + Ca) 1-2%; "Ulco metal"  $\left\{ \begin{array}{l} UTS = 9.1\ \text{kg/mm}^2 \\ EL = 5\% \text{ on } 1\ \text{in.} \\ RA = 1\% \end{array} \right\}$  (9).Ba, 1.30; Ca, 0.79  $\left\{ \begin{array}{l} BHN = 31.2_u; 26.5_v \\ ScH = 7.5; 13.5_m \end{array} \right\}$  (31), where  
u = 500 kg; v = 1000 kg; m = magnifier hammer.

Pb, ca. 97.5; Ba, &lt;2; Ca, &lt;1; Hg, 0.25

$t$ , °C	25	50	100	150	
$BHN$ .....	29.6	27.2	20.9	14.0	"Frery metal" (8)



## PB-SB (CAST) (11)

% Sb	UTS	EL <sub>a</sub>	RA
0.0	1.25*		
2.6	3.16	15	21.6
3.9	3.71	19	25.0
4.5†	4.36	35.5	34.5
5.0	4.42	28.5	27.5
6.1	4.75	21.8	23.3
7.4	4.96	19.3	21.0
8.1	5.24	21.5	22.1
9.9	5.39	15.5	13.6
12.6	5.17	11.0	10.6
14.0	4.94	8.8	9.3
19.6	4.40	1.8	1.5
24.7	4.26	1.3	0.4

\* (23).

† Density = 10.5 (5).

## PB, 92; SB, 8, \* HARD PB (R) (5)

Thickness, mm	UTS	EL	ScH
0.89	3.89	14.8	3-4
1.07	3.82	15.2	3-4
1.27	4.16	19.0	3-4

\* Density = 10.71 (5).

## PB-SB-SN (33)

v. also Pb-Sn-Sb-Cu

Pb, 88.8; Sb, 7.5; Sn, 3.7	UTS = 5.7
83.3      9.8      6.9	8.7
78      7      15	6.23

## PB-SN

% Sn	Trt	UTS	BHN	Lit.
0	G	1.25*	4.2	(6)
10			10.1	(34)
20			12.2	(34)
30			14.5	(34)
33.3		7.63		(33)
40			15.8	(34)
50		7.1	18.0	(33, 34)

\* (23).

## PB-SN-SB-CU, BEARING ALLOYS (30)

v. also Pb-Sb-Sn

% composition				d <sub>4</sub> <sup>18</sup>	BHN	UTS	EL <sub>a</sub>	UCS*	YPC*
Pb	Sn	Sb	Cu						
80	5	15		10.04	25†	7.4	2.8	21.1	5.7
63.5	20	15	1.5	9.33	25‡	8.7	0.0	19.2	6.3
48.5	40	10	1.5		22	7.2	0.0	17.8	5.8

\* YPC at Δl = -0.2% l<sub>0</sub>, UCS at Δl = -0.5l<sub>0</sub>.

† BHN = 10 at 100°C.

‡ BHN = 11 at 100°C.

## SB

UTS = 1.1 kg/mm<sup>2</sup> (wire 0.36 mm diam.) (3).E = 7950 kg/mm<sup>2</sup>, G = 2020 kg/mm<sup>2</sup> (from bending tests on wires) (3).

## SN

Treatment	UTS	EL <sub>a</sub>	BHN	CS*	EL <sub>C</sub>	Lit.
Rolled.....	2.5					(19)
Annealed.....	1.7					
Pr, A 100°.....	1.9	86	5.0	3.6	0.08	(7)
Cast.....			5.2	2.8		

E = 4000 - 5500 kg/mm<sup>2</sup>. G = 1700 kg/mm<sup>2</sup> (19).\* Δl = -32% l<sub>0</sub>.

## SN-PB (23, 33, 34)

% Pb	0	10	20	30	34	40	% Pb	0	37
BHN	5.2	13.3	15.2	15.8	16.7	14.6	UTS	2.46	7.64

Composition	BHN	UTS	EL <sub>a</sub>	UCS*	YPC*
-------------	-----	-----	-----------------	------	------

## Sn-Pb-Sb-Cu, bearing alloys (30)

Sn, 80; Pb, 6; Sb, 11; Cu 3	32	9.0	0.0	27.6	5.7
60      28.5      10      1.5	27	7.9	0.0	20.2	6.3

## Sn-Sb-Cu, bearing alloys (30)

Sn, 93; Sb, 3.5; Cu, 3.5	25	3.0	11.6	23.1	5.7
86      10.5      3.5	33	10.2	7	26.8	6.9
78      11      11	37	11.5	0.0	18.0	7.1

Sn, 91; Sb, 4.5; Cu, 4.5: d<sub>4</sub><sup>18</sup> = 7.34; Sn, 89; Sb, 7.5; Cu, 3.5: d<sub>4</sub><sup>18</sup> = 7.39.\* YPC at Δl = -0.2% l<sub>0</sub>, UCS at Δl = -0.5l<sub>0</sub>.

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(For a key to the periodicals see end of volume)

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# PROPERTIES OF COMMERCIAL COPPER, ORDINARY, PHOSPHOR, AND ZINC BRONZES AND COPPER-BASE BEARING ALLOYS

S. L. HOYT

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## CU, COMMERCIAL COPPER

See also Figs. 1 and 2 and p. 552

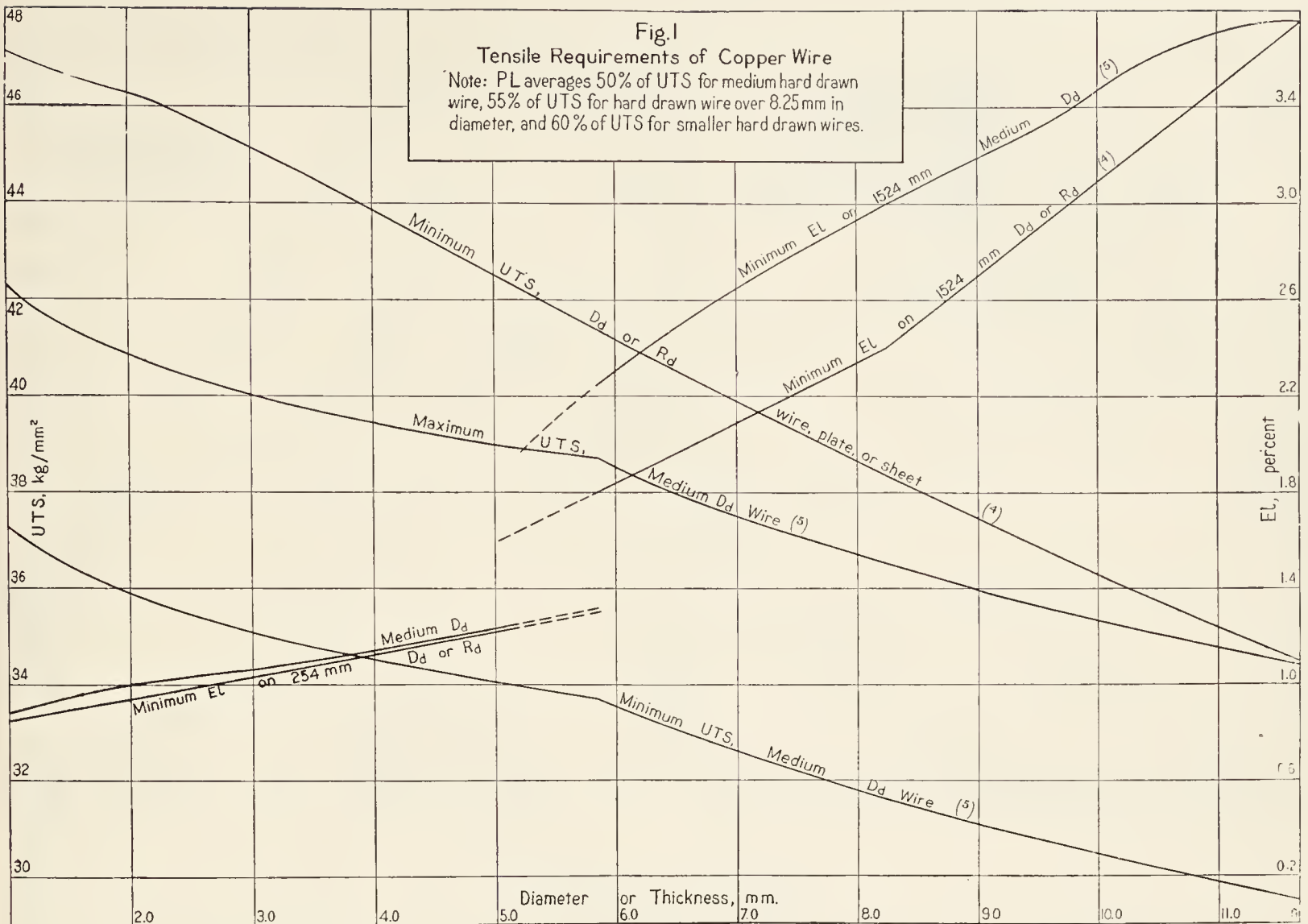
% Cu	Description and treatment	UTS	PL	El	RA	BHN	ScH	Lit.
99.9	Normalized* pure copper.....	21-28	†	40-60	40-60	30-40		(13)
	Cast.....	14.2		17.2 <sub>b</sub>				(45)
	Same { A 540°/1 w Q <sub>w</sub> .....	16.6		22.6 <sub>b</sub>				
	W R Q <sub>w</sub> .....	18.0		28.5 <sub>b</sub>				
≥99.5	Pure sheet copper.....							(48)
	Soft, 0.13-0.79 mm thick.....	26.0‡		20.0				
	Soft, 0.81-9.51 mm thick.....	25.3‡		25.0				
	Hard, 1.83-9.51 mm thick.....	28.1		8.0				
	Hard, >9.51 mm thick.....	26.4		15.0				
99.6	Cast.....	17.6	7.0	20	60	40	8	(14)
	Same, R <sub>d</sub> 40%.....	35.2	14.1	5	8	94		
	Annealed at 500°C.....	24.6		50	60	42	6	
	D <sub>e</sub> 50%; v. also (36).....	35.2	26.0	9			18	
	Cast boronized copper.....	17.0	8.0	48.5	74.5			(54)
	Fire-box copper, R, A.....	23.0		35-38	45-50			(33)
	Special stay bolt Cu, A.....	27.0		35-38	45-50			

\* Best normalized by casting, rolling, drawing, followed by annealing at 500°. † No definite PL. ‡ Maximum. || Minimum.

For properties of cold drawn copper wire, v. Fig. 2.

For tensile requirements of copper wire, v. Fig. 1.





## CU-SN, BRONZE

Cast in graphite mold (45); v. also Figs. 3-8

% Sn	Treatment	UTS	El <sub>b</sub>
2	G <sub>hm</sub> .....	19.4	21.8
	A 540°/1 w Q <sub>w</sub> .....	20.3	31.0
4	G <sub>hm</sub> .....	22.9	20.5
	A 540°/1 w Q <sub>w</sub> .....	25.2	23.2
	W R Q <sub>w</sub> .....	22.6	18.5
6	G <sub>hm</sub> .....	24.1	15.3
	A 540°/1 w Q <sub>w</sub> .....	23.8	21.8
	W R Q <sub>w</sub> .....	23.9	20.0
8	G <sub>hm</sub> .....	28.8	11.5
	A 540°/1 w Q <sub>w</sub> .....	24.9	25.1
	W R Q <sub>w</sub> .....	25.9	20.5
10	G <sub>hm</sub> .....	29.5	12.7
	A 540°/1 w Q <sub>w</sub> .....	30.4	36.4
	A 400°/1 w C <sub>f</sub> .....	28.6	24.7
	W R Q <sub>w</sub> .....	31.4	21.0
13	G <sub>hm</sub> .....	29.0	5.1
	A 540°/1 w Q <sub>w</sub> .....	31.7	32.8
	A 400°/1 w C <sub>f</sub> .....	26.8	10.0
	W R Q <sub>w</sub> .....	29.5	8.3
	W 620° Q <sub>w</sub> .....	33.3	17.5
16	G <sub>hm</sub> .....	27.8	1.5
	A 540°/1 w Q <sub>w</sub> .....	35.2	19.6
	A 400°/1 w C <sub>f</sub> .....	28.6	2.0
	W R Q <sub>w</sub> .....	41.4	9.5
	W 620° Q <sub>w</sub> .....	38.3	9.0

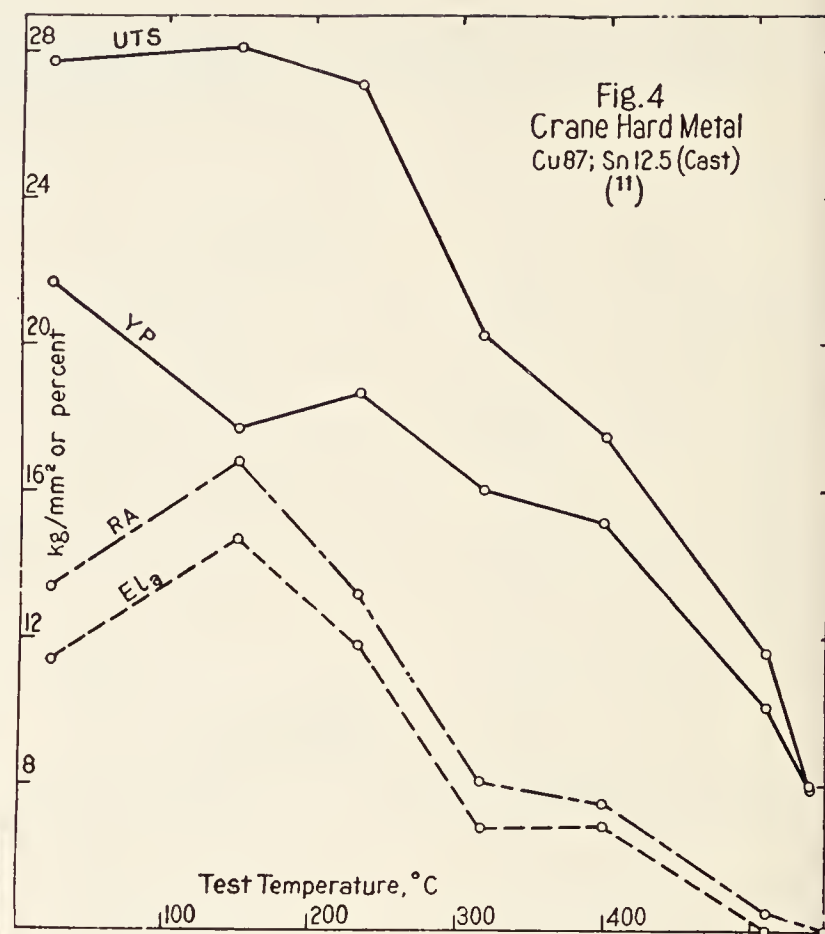
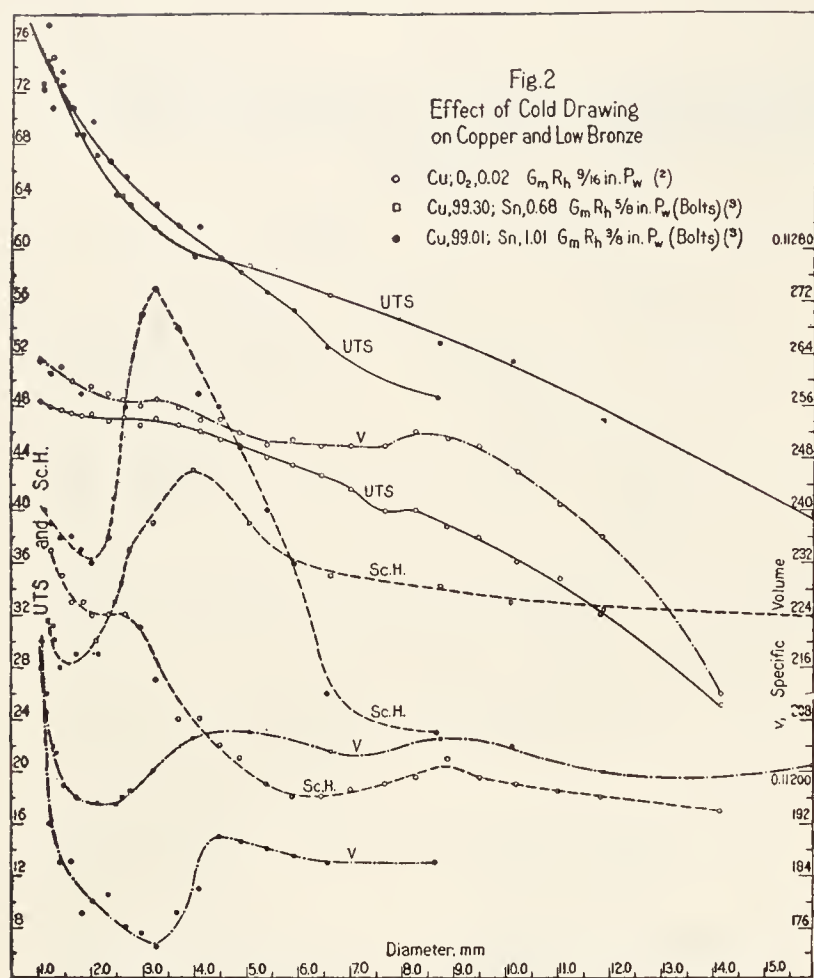
## CU-SN, BRONZE.—(Continued)

Cast in graphite mold (45); v. also Figs. 3-8

% Sn	Treatment	UTS	El <sub>b</sub>
19	G <sub>hm</sub> .....	37.7	2.9
	G C <sub>a</sub> .....	26.3	0.3
	G <sub>m</sub> (cold) .....	23.0	0.2
	A 540°/1 w Q <sub>w</sub> .....	38.7	
	A 400°/1 w C <sub>f</sub> .....	28.5	0.5
	W R Q <sub>w</sub> .....	44.1	6.3
	W 620° Q <sub>w</sub> .....	47.0	6.5
	W 720°/45 Q <sub>w</sub> .....	45.7	5.0
22	G <sub>hm</sub> .....	31.6	0.4
	A 540°/1 w Q <sub>w</sub> .....	39.1	
	A 610°/1 h Q <sub>w</sub> .....	40.0	5.3
	A 400°/1 w C <sub>f</sub> .....	17.6	
	A 400°/1 h C <sub>a</sub> .....	Cracked	
	W 700° C <sub>a</sub> .....	12.4	0.05
	W R Q <sub>w</sub> .....	44.5	1.3
	W 700° Q <sub>w</sub> .....	39.9	1.0
25	G <sub>hm</sub> .....	9.9	Nil
	A 540°/1 w Q <sub>w</sub> .....	17.7	
	A 400°/1 w C <sub>f</sub> .....	11.7	
	W 630°/1 h Q <sub>w</sub> .....	22.2	0.8
	W 600°/1 h Q <sub>w</sub> .....	25.8	0.4
	W 700°/1 h Q <sub>w</sub> .....	23.6	1.1
30	G <sub>hm</sub> .....	11.1*	
	A 400°/1 w C <sub>f</sub> .....	2.5*	

\* Some specimens of this composition broke while being gripped.

For properties of cold drawn bronze, v. Fig. 2.



## Cu-Sn-P, PHOSPHOR BRONZE

See also Figs. 9 and 10

% Sn	% P	Index No.	Treatment	UTS	Y = YP P = PL	El	RA	BHN	ScH	Lit.
3.77	0.16		D (rod).....	56.0	41.7 <sub>Y</sub>	17.5	57			(42)
4	Tr.		G.....	23	11 <sub>Y</sub>	15-20		50-60		
			Wk.....	39						
			Wk, A.....	31.5						
			R <sub>c</sub> , A.....	32			80			
			D.....	84-112						
			D, A.....	28-35						
4.7*	Tr.		G <sub>s</sub> .....	24.3	5.7 <sub>P</sub>	22	18.2	56.8	20.4	(42)
	1.2		G <sub>m</sub> .....	34.1	6.0 <sub>P</sub>	12.7 <sub>5</sub>	12.4	69.1	16.2	
4.9	0.1		R.....	45.7	28.2 <sub>P</sub>	30.0			37	(14)
6	Tr.		G.....	23	11 <sub>Y</sub>	15-20				
			D.....	84-112						
			D, A.....	28-35						
10†	0.4		G <sub>s</sub> .....	20.9	6.3 <sub>P</sub>	6.0	8.5	70	21	(42)
			G <sub>m</sub> .....	23.8	5.0 <sub>P</sub>	4.0	4.9	84	20	
10	Tr.		G.....	23	12.5-14 <sub>P</sub>	15-20	10-17			(18)
			G <sub>am</sub> .....	30						
10-12	0.1-0.3	612	G.....	24.6	14.1 <sub>Y</sub> §	10§				(47)
11	0.3	1359	G.....	24.6-28.4	15.8-17.3 <sub>Y</sub>	6-10	7-9	80		(56)
15‡	0.6		G <sub>s</sub> .....	17.6	8.5 <sub>Y</sub>	3.0	1.8	80	25	(42)
			G <sub>m</sub> .....	23.6	9.5 <sub>Y</sub>	1.0	1.5	94	24	

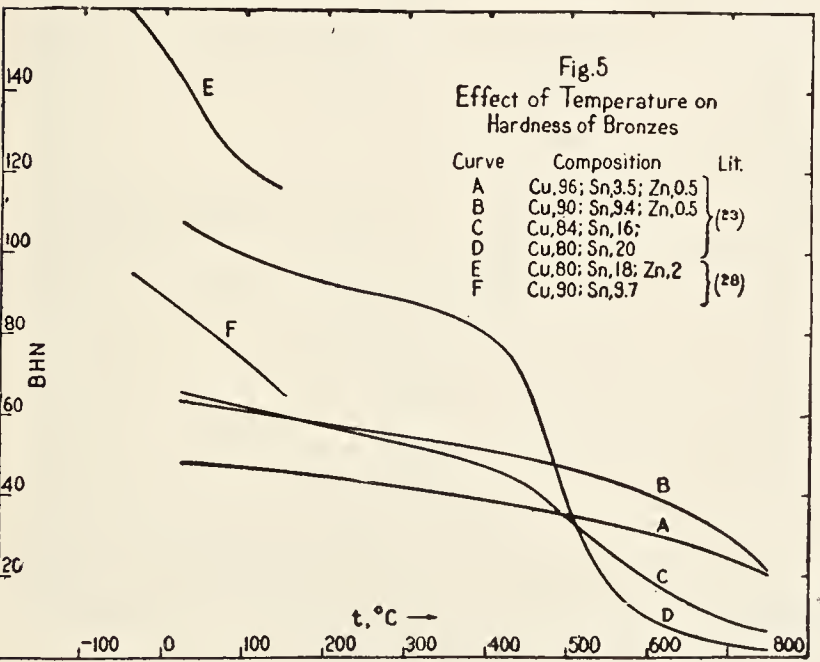
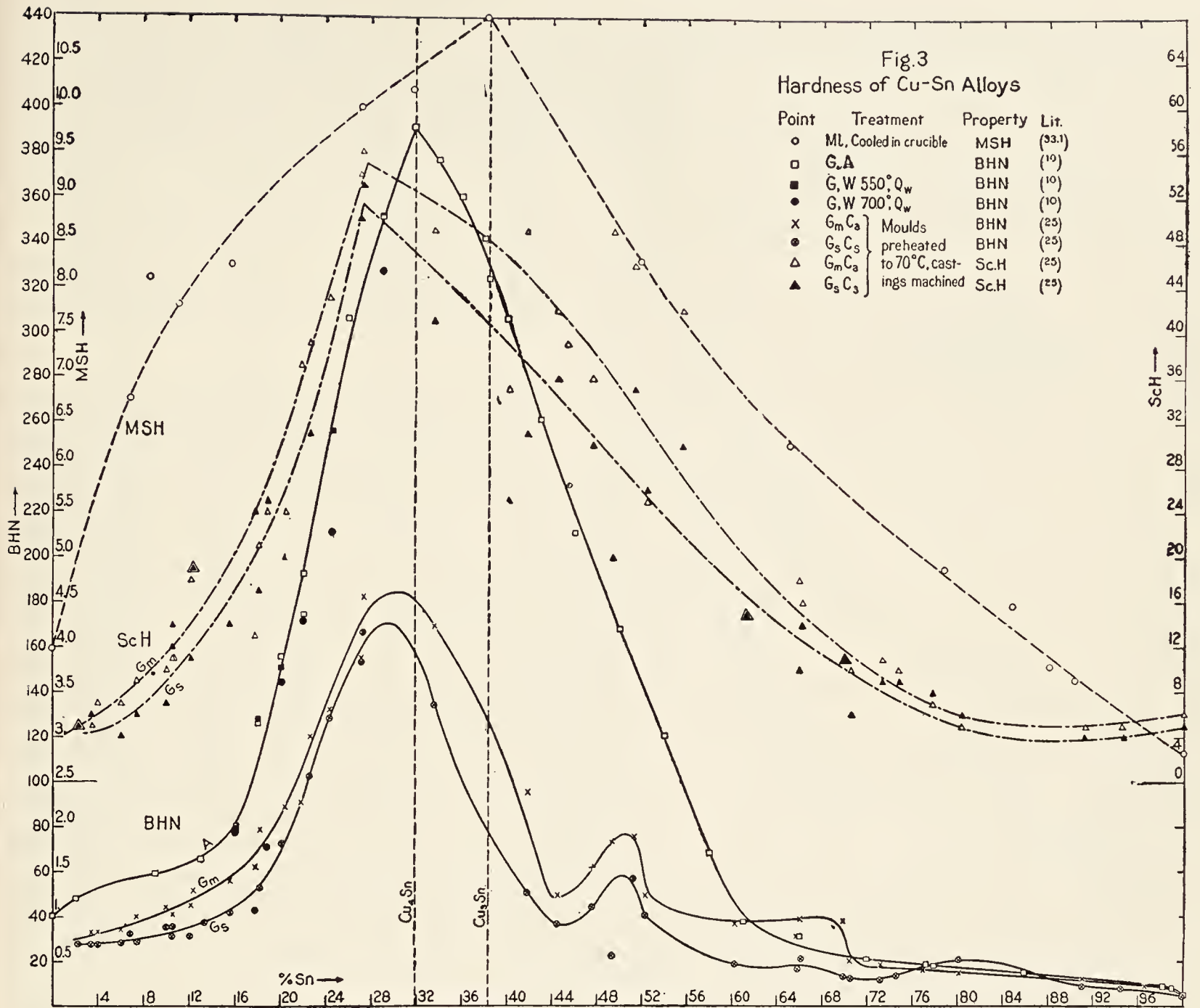
\* Malleable, typical analysis: Cu, 94.0; Sn, 4.7; P, 1.17; As, 0.15; Pb, 0.11; (Sb, Fe, Al, Zn), Tr.

† Typical analysis: Cu, 89.8; Sn, 9.3; P, 0.44; As, 0.39; Pb, 0.03; (Sb, Fe, Zn), Tr.; Al, 0.

‡ Typical analysis: Cu, 84.8; Sn, 14.3; P, 0.6; Sb, 0.15; Fe, 0.1; Pb, 0.08; As, 0.06.

§ Minimum.



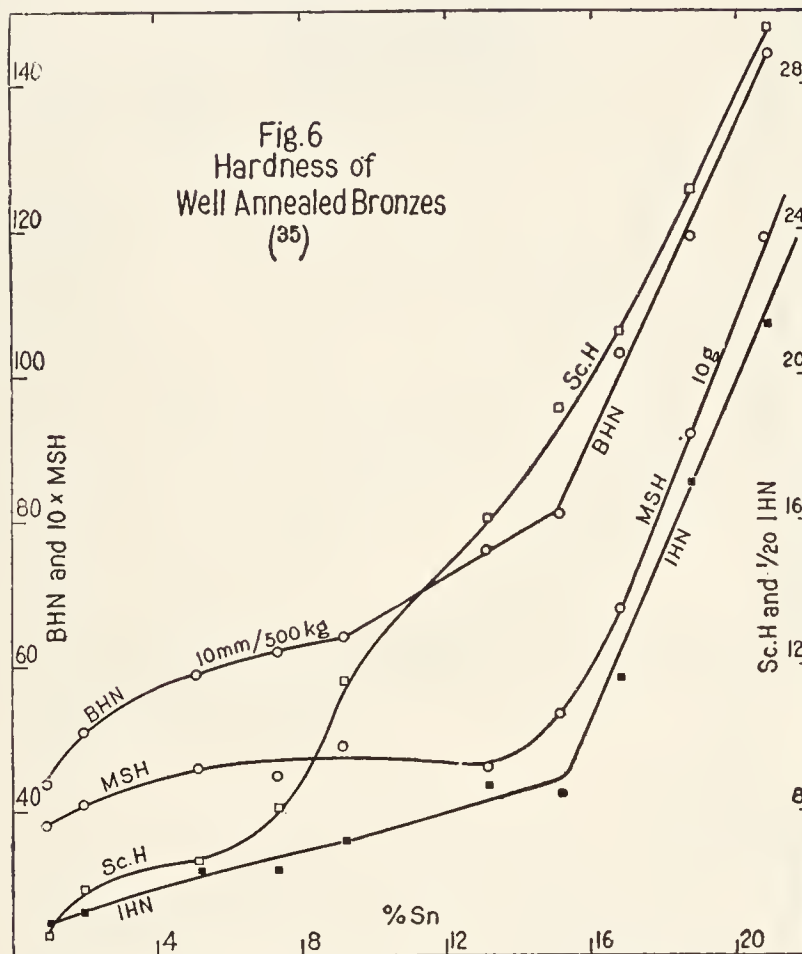


MECHANICAL PROPERTIES OF COPPER-BASE BEARING ALLOYS AS CAST (CAR JOURNAL BEARINGS) (16)

% composition				UTS	El <sub>a</sub>	PLC	ε at 70.3 kg/mm <sup>2</sup>	ScH
Cu	Sn	Pb	Zn					
95	5			29.4	34.5	12.7	31	23
90	5	5		28.5	34.5	13.4	32	15
	10			27.4	15	17.6	26	23
85	5	5	5	26.8	36	12.7	33	14
	5	10		22.0	19.5	12.7	36	14
	10	5		23.0	9.5	15.5	26	19
80	5	5	10	19.8	15	12.7	32	16
	5	10	5	24.4	23	11.3	34	18
	5	15		16.4	15.5	11.3	39	14
	10	5	5	23.6	3.5	19.0	21	21
	10	10		22.4	8.5	16.2	29	21
75	5	5	15	19.0	10	12.0	28	18
	5	15	5	22.0	19	13.0	19	19
	5	10	10	21.0	13	13.4	32	18
	5	20		16.4	15.5	10.5	12	12
	10	5	10	17.2	1.0	19.0	19.5	25
	10	10	5	22.0	2.5	20.0	22	21
	10	15		19.0	6	16.2	32	15
70	5	25		17.4	14	11.6	12	12
	5	10	15	20.0	10	13.0	30	20
	5	20	5	19.8	20	12.3		15

MECHANICAL PROPERTIES OF COPPER-BASE BEARING ALLOYS AS CAST (CAR JOURNAL BEARINGS) (16).—(Continued)

% composition				UTS	El <sub>a</sub>	PLC	ε at 70.3 kg/mm <sup>2</sup>	ScH
Cu	Sn	Pb	Zn					
79	10	20		19.0	6	14.8		19
	10	5	15	19.3	1.5	28.1	17	28
	10	15	5	19.8	1.5	18.3		23
	10	10	10	21.1	4.7	20.4	17	22
65	5	30		13.9	12	10.5		10



CU-PB-SN, MECHANICAL PROPERTIES OF BEARING BRONZES (AS CAST)

See also Fig. 11

% composition						Index No.	UTS	El	RA	BHN†	UCS	DL <sub>C</sub>	CS	ε	Lit.
Cu	Pb	Sn	Zn*	P	S*										
85	5	10	0.25	0.70†	0.05	211	19.7	12.5 <sub>a</sub>		60		12.6§	70.3	26	(6,33)
80	10	10	0.50	0.70†	0.05	212	17.6	8 <sub>a</sub>		55		10.5§	70.3	29	(6,33)
80	10	10	2.00	0.05*	0.05	213	15.5	8 <sub>a</sub>		50		8.8§			(6)
79.7	9.5	10		Tr.			16.8	2.9		55.0					(21.1)
79.7	9.5	10		0.8		1326	21.1	6							(33)
77	15	8	0.50	0.25*	0.05	214	14.1	10 <sub>a</sub>		48		8.4§			(6)
77	15	8	0.2			553	16.9	11				14.8			(21.1,33)
73	20	7	0.50	0.05*	0.25	215	12.7	7 <sub>a</sub>		45		7.7§			(6)
70	20	10			ca. 1	55					64.6	16.2			(3.1)
70	25	5	0.50	Nil	0.25	216	10.5	5 <sub>a</sub>		40		7.0§			(6)
67	24	9			ca. 1	55					56.8	21.8			(3.1)
64.75	30	5				456	12.2	6.5		41.3					(33)
64	30	5		Ni, 1.0		34	15.0	10.1 <sub>a</sub>	8.20	40.0			45.3	44	(33)
62.5	30	7.5		S, ca. 1		55					53.7	13.7			(3.1)
60.67	32.97	4.60		Ni, 2.1		469	12.8	3.0 <sub>a</sub>	0.35	52.0			39.5	30.4	(33)
58.5	35	6.5		S, ca. 1		55					45.0	10.5			(3.1)
55	40	5		S, ca. 1		55					31.9	9.8			(3.2)
50	50									21.8					(33)

\* Maximum in the alloys of (6), also: Fe, &gt;0.25; Sb, &gt;0.50; Al, 0.

† 10 mm, 500 kg; v. also *infra*.

‡ Minimum.

|| On 8 in.

§ Load producing ε = 0.1 % in specimen 1 in.<sup>2</sup> cross-section by 1 in. long.

WEAR AND FRICTIONAL PROPERTIES OF COPPER-BASE BEARING ALLOYS

Mean values from service tests on the Pennsylvania R. R. (21.1)

% composition					Index No.	Relative wear
Cu	Pb	Sn	P	As		
89.2		10.0		0.8		1.42
87.5		12.5				1.47-1.53
79.7	9.5	10.0	0.8		1326	1.00
79.7	9.5	10.0		0.8		1.01
79.2	7.0	10.0		0.8		1.15
77.0	12.5	10.5			556	0.92-0.93
77.0	15.0	8.0			553	0.865

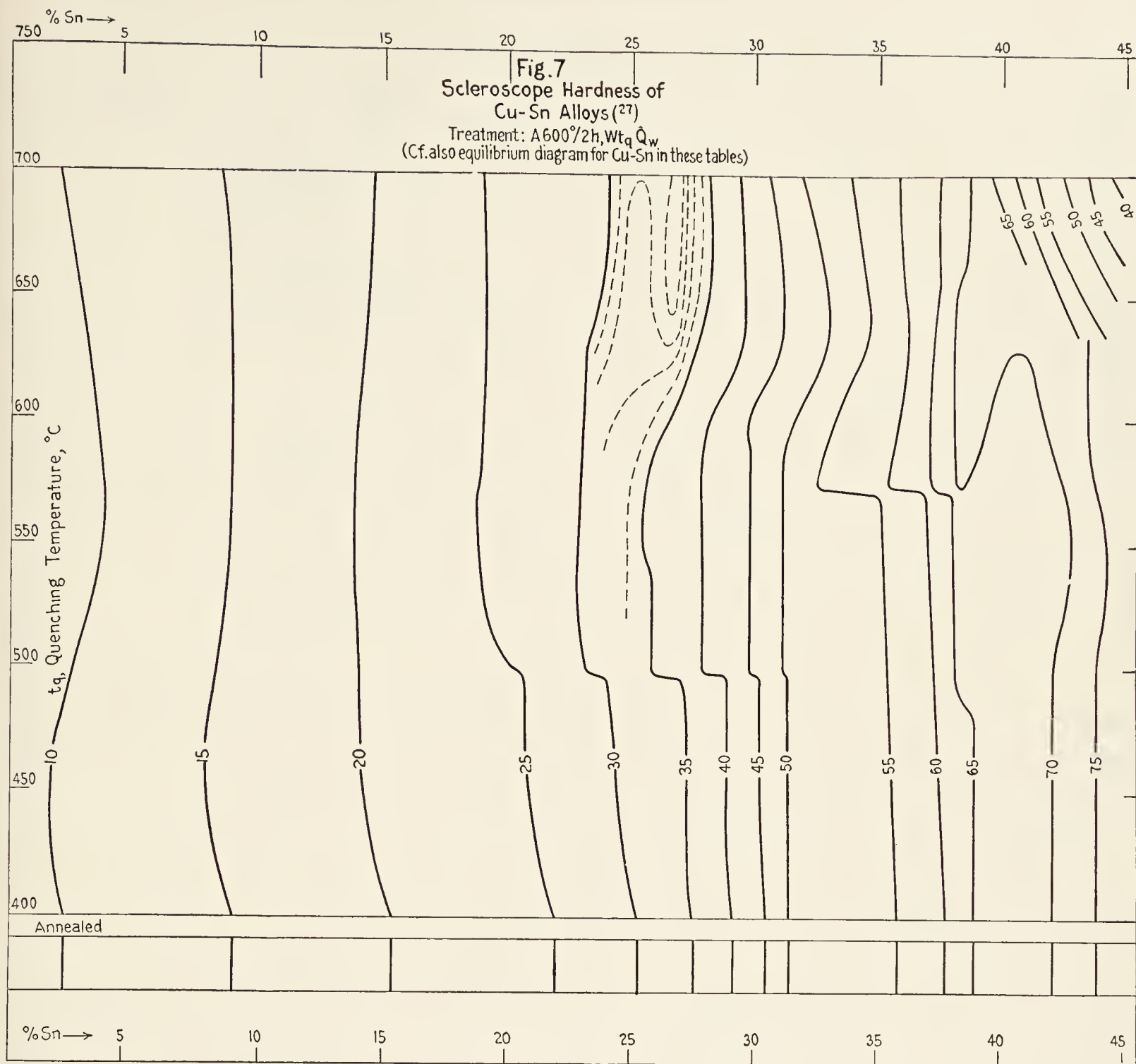
LABORATORY TESTS ON THE CARPENTER MACHINE\* (16)

% composition				Friction, kg	Temp. rise, °C	Wear in mg	Relative wear†
Cu	Pb	Sn	Zn				
95.0		4.95		7.3	29	4.96	0.49
90.7		9.45		5.9	28.5	11.45	1.13
85.8		14.9		5.9	28	18.14	1.79
90.8	4.8	4.6		6.4	29.5	3.51	0.35
85.1	10.6	4.6		8.4	31	2.46	.24
81.3	14.1	5.2		8.4	32	2.12	.21
75?	20?	5?		8.4	32	1.80	.18
68.7	26.7	5.2		8.2	32	1.32	.13
64.3	31.2	4.7		8.2	35.5	0.84	.08
83.3	10.3	5.3	2.1	8.4	38	2.69	0.27
79.8	10.3	4.7	5.4	8.4	36.5	3.02	.30
77.4	11.4	5.6	6.5	8.4	38	3.06	.30
74.3	10.5	4.7	11.0	8.4	38.5	5.48	.54

\* Total number of revolutions = 100 000; speed = 525 r.p.m.; bearing 3 3/4 in. diam. × 3 1/2 in. long; load = 0.7 kg/mm<sup>2</sup>; lubrication, Galena coach oil fed by cotton waste.

† Comparison with above results on basis of (38.1) according to which wear of Cu-Sn is approximately proportional to Sn content, more exactly to % of S constituent.





Cu-Sn-Zn, ZINC BRONZE

See also Fig. 12

% composition			Treatment	UTS	YP	PL	El	RA	BHN	ScH	Lit.
Cu	Sn	Zn									
90	6	4	D <sub>c</sub> , 3.5-3 mm diam.....	57.3			9.5				(53)
			D <sub>c</sub> , A $\left\{ \begin{array}{l} 400^{\circ} \\ 600^{\circ} \\ 800^{\circ} \end{array} \right\}$ 1 h C <sub>a</sub> .....	53.1 38.4			17.3 51.8				
			D <sub>c</sub> , A $\left\{ \begin{array}{l} 400^{\circ} \\ 600^{\circ} \\ 800^{\circ} \end{array} \right\}$ 1 h Q <sub>w</sub> .....	32.7 52.3 39.3 34.0			51.3 22.0 51.3 51.0				
90	9.5	0.5	G.....	22.5							
88	8	4	G <sub>a</sub> at 1100-1140°.....	30.4		8.4	36 <sub>a</sub>	28.0			(49)
88	8	4*	G.....	23-26	14-17.5		25-30		55-75		(18)

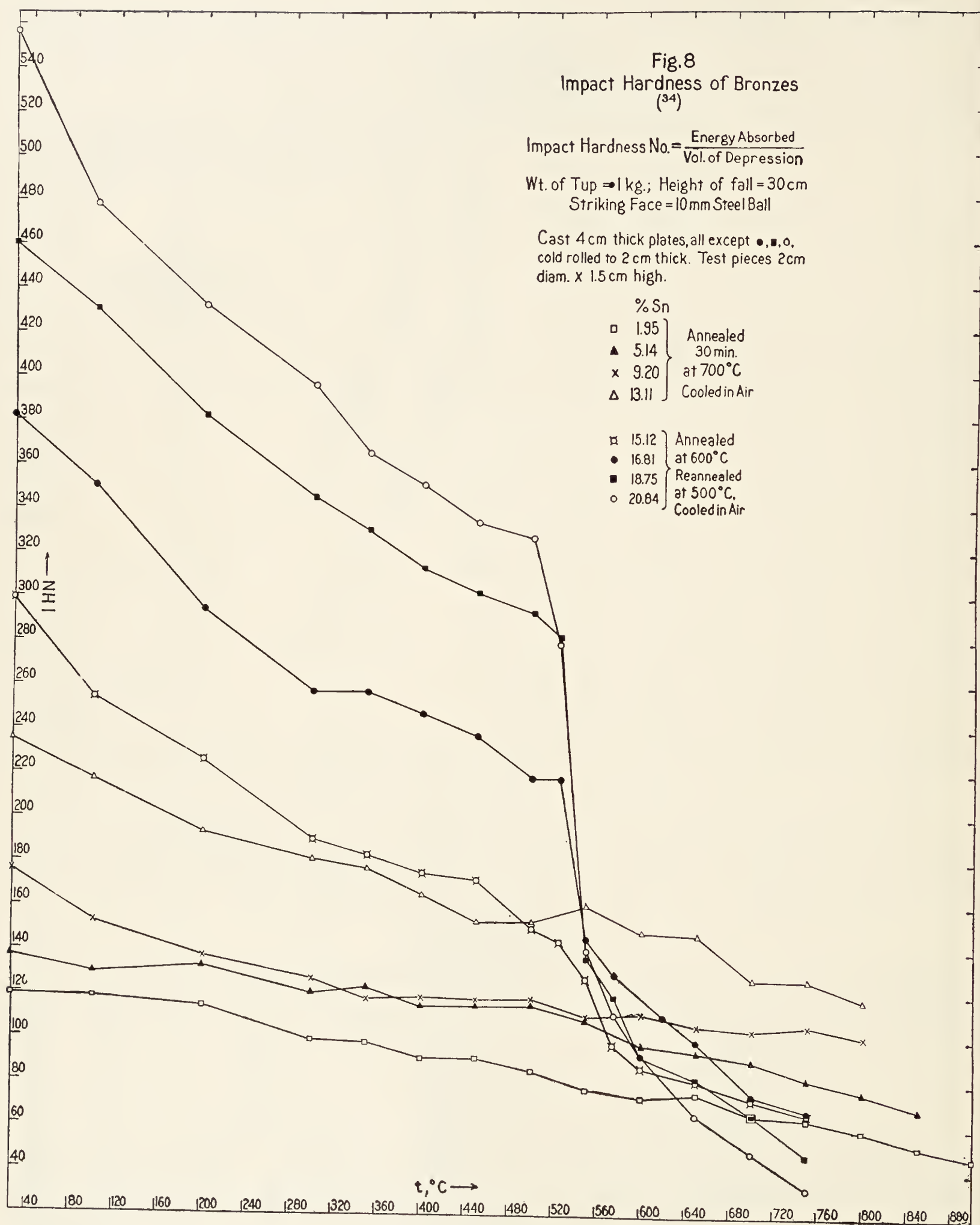
Continued on p. 565.

Fig. 8  
Impact Hardness of Bronzes<sup>(34)</sup>

$$\text{Impact Hardness No.} = \frac{\text{Energy Absorbed}}{\text{Vol. of Depression}}$$

Wt. of Tup = 1 kg.; Height of fall = 30 cm  
Striking Face = 10 mm Steel Ball

Cast 4 cm thick plates, all except ●, ■, ○, cold rolled to 2 cm thick. Test pieces 2 cm diam. x 1.5 cm high.



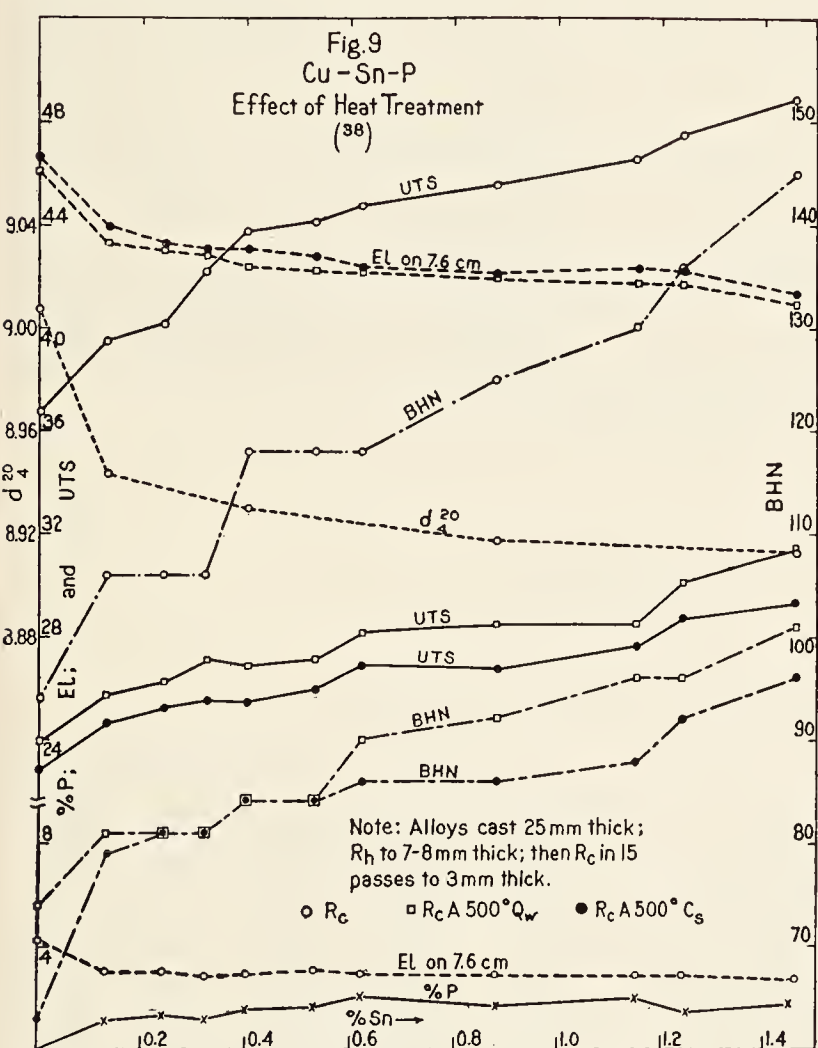


## CU-SN-ZN, ZINC BRONZE.—(Continued)

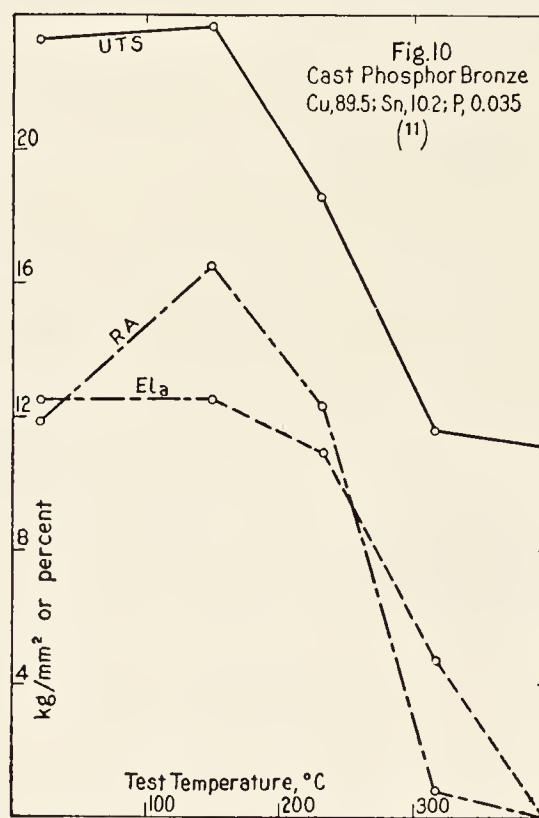
See also Fig. 12

% composition			Treatment	UTS	YP	PL	El	RA	BHN	ScH	Lit.
Cu	Sn	Zn									
88	10	2	G <sub>s</sub> at 1200°	26.8	16.4		14.0		77	16	(40)
			ML <sub>2</sub> , G <sub>s</sub> at 1200°	26.8	14.0		17.2		79	14	
			G <sub>s</sub> at 1060°†	24.6			28.0		62		(39)
			G <sub>m</sub> at 1060°	23.6			4.0		86		
			G <sub>s</sub>	30	11-12.5						(46)
			G (U. S. N. Spec. G)	24.7	13.7	7.4	22.5	23.1			(17)
			G (U. S. N. Spec. Pc-2)	25.8	12.5	7.2	25.5	31.7			
For effect of heat treatment on this alloy <i>v. infra</i> .											
87	8	5	G <sub>s</sub> at 1200°	26.5	13.1		18.7		80	18	(41)
			ML <sub>2</sub> , G <sub>s</sub> at 1200°	24.4	13.1		15.6		83	19	
86	9	5	G <sub>s</sub>	16-24			2.5-8		55-75		(20, 21)
			G <sub>m</sub>	16-22			2.5-8		75-90		
86	13	1*	G	26	14-17.5		4-8		85-120		(18)
85	5	10	G <sub>s</sub> at 1200°	25.2	12.3		25.0		69	15	(41)
			ML <sub>2</sub> , G <sub>s</sub> at 1200°	24.4	12.1		23.4		69	15	

\* Contains trace of P. † In dry sand.

EFFECT OF CASTING TEMPERATURE AND HEAT TREATMENT OF  
Cu, 88; Sn, 10; Zn, 2"Admiralty bronze," "U. S. Government bronze Spec. G,"\*  
*v. also Fig. 12*

Treatment	UTS	El <sub>a</sub>	RA	BHN	Lit.
Cast in dry sand at:	1050°	29.7	20.5	13.5	(29)
	1120°	30.9	20.5	14.0	
	1220°	28.1	17.0	16.2	
	1255°	28.0	15.5	13.0	
Chilled cast at:	1120°	34.7	5.5	4.0	(29)
	1220°	34.9	6.0	7.0	
	1255°	23.9	15.0	12.1	



Treatment	UTS	El <sub>a</sub>	RA	BHN	Lit.
G <sub>s</sub> (dry sand)† at . . . . . ca. 1060°	24.6	28.0		62	(39)
Same heated slowly to . . . . . { 500° 600° 700° 800° } Q <sub>w</sub>	12.9	12.0		77	
	10.2	7.5		65	
	7.7	3.0		61	
	14.2	5.5		74	
G <sub>s</sub> to size† . . . . .	30.2	11-12.5			(46)
Same heated 30 min at: { 495° 540° 595° 650° 705° 760° } Q <sub>w</sub>	31.2	9.4			
	31.7	15.6			
	33.7	20-22			
	13-16.6	4.7-11			
	13-17.5	8-11			
G <sub>s</sub> , heated 30 min at: { 495° 540° 595° 650° } Q <sub>o</sub>	11.7	6.5-7.5			(46)
	26.1	9.4			
	31.3	18.8			
	33.5	28.0			
G <sub>s</sub> , heated 30 min at: { 495° 540° 595° 650° } C <sub>a</sub>	26.7	28.0			(46)
	29.3	9.4			
	33.7	26.5			
	35.8	53.0			
	30-35.5	25-50			

EFFECT OF CASTING TEMPERATURE AND HEAT TREATMENT OF  
CU, 88; SN, 10; ZN, 2.—(Continued)

Treatment	UTS	El <sub>a</sub>	RA	BHN	Lit.
G <sub>s</sub> †.....	27.1	24.0		63	(39)
Same annealed 30 min at:§	500° 23.8	26.5		65	
	600° 25.7	28.5		61	
	700° 28.4	37.5		60	
	800° 24.4	31.0		60	
Sand cast, annealed 30 min at: (C <sub>f</sub> > 24 h)	495° 26-29	12.5-15.5			(46)
	540° 32.0	18.8			
	595° 31.0	37.5-81			
	650° 29.8	28.0			
	705° 32.5-35	37.5-50			
	760° 29.5-31	32.9			
Chill cast.....	23.6	4.0		86	(29)
Same annealed 30 min at:	500° 19.4	7.5		80	
	600° 30.9	25.0		75	
	700° 31.5	30.0		74	
	800° 27.1	22.5		70	
Chill cast.....	25.2	6	7		(39)
Same annealed 30 min at:	500° 24	7.5	16		
	600° 27	19	19		
	700° 28-35	26	22		
	800° 19	17	18		

\* For effect of other casting conditions, v. (4).

† Specimens 5/8 in. diam. × 2 in. gage length, machined before heat treatment.

‡ Gaged portion: 0.5 in. diam.

§ Gradually heated to t<sub>c</sub>, cooled at moderate rate to 400°C, then cooled slowly.CU-SN-ZN-AS, EFFECT OF ADDING AS TO ADMIRALTY GUN METAL  
(17)

% composition						t <sub>c</sub> , °C*	Trt†	UTS	YP‡	El <sub>a</sub> §
Cu	Sn	Zn	As	Pb	Fe					
88.14	9.97	1.67	0.04	0.08	0.07	1220	G <sub>s</sub>	27.3	15.4	16.7
						1250	G <sub>m</sub>	22.8	18.7	4.5
88.20	10.28	1.34	.04	.08	.05	1240	Ml <sub>2</sub> G <sub>s</sub>	23.8	15.8	11.0
						1280	Ml <sub>2</sub> G <sub>m</sub>	23.0	16.5	4.3
87.74	10.30	1.39	.42	.08	.05	1220	G <sub>s</sub>	26.3	15.0	9.0
						1250	G <sub>m</sub>	23.8	18.3	4.5
87.98	10.35	1.08	.42	.08	.08	1250	Ml <sub>2</sub> G <sub>s</sub>	23.9	15.1	11.0
						1280	Ml <sub>2</sub> G <sub>m</sub>	23.2	17.0	3.4
88.20	9.89	0.58	1.01	.12	.12	1220	G <sub>s</sub>	23.5	15.5	7.8
						1240	G <sub>m</sub>	23.9	18.7	5.0
88.35	9.86	0.49	1.01	.12	.12	1240	Ml <sub>2</sub> G <sub>s</sub>	24.2	15.5	10.1
						1280	Ml <sub>2</sub> G <sub>m</sub>	23.6	17.6	3.8

\* t<sub>c</sub> = casting temperature.† Bars cast vertically 1 in. diam. × 15 in. long; sand cast ones in green sand.  
All molds preheated.

‡ By dividers.

§ Test piece diameter = 0.798 in. All values in this table are means from two test pieces.

## CU-SN-ZN-PB, EFFECT OF ADDING LEAD TO ZINC BRONZES (49)

% composition				t <sub>c</sub> , °C*	Trt	UTS	PL	El†	RA
Cu	Sn	Zn	Pb						
88	10.0	2	0	1100-1140	G <sub>s</sub>	30.3	9.2	29.7	24.3
88	8.0	4	0	1100-1140	G <sub>s</sub>	30.4	8.4	36.0	28.0
90	6.5	3	0.5	1090-1125	G <sub>s</sub>	28.6	9.6	37.6	34.1
				1170-1200	G <sub>s</sub>	26.4	9.1	28.1	29.7
				1090-1200	A‡	25.1	9.3	24.9	23.2
90	6.5	2	1.5	1080-1136	G <sub>s</sub>	28.6	8.6	35.3	31.8
				1170	G <sub>s</sub>	25.2	7.3	25.5	32.5
				1080-1170	A‡	29.0	9.6	37.2	33.6
90	6.5	1	2.5	1100-1140	G <sub>s</sub>	27.8	9.3	27.2	27.7
				1150-1200	G <sub>s</sub>	23.6	8.7	18.6	19.7
				1100-1200	A‡	24.4	9.8	20.1	23.5
90	5.5	4	0.5	1060-1120	G <sub>s</sub>	26.6	8.7	29.3	30.4
				1160-1180	G <sub>s</sub>	26.5	8.1	31.6	32.4
				1060-1180	A‡	26.1	9.3	24.2	27.3
90	5.5	3	1.5	1060-1140	G <sub>s</sub>	25.4	7.5	31.4	28.4
				1160-1180	G <sub>s</sub>	21.7	6.8	22.8	18.6
				1060-1180	A‡	25.7	8.4	28.5	26.7
90	5.5	2	2.5	1100-1120	G <sub>s</sub>	25.2	7.6	23.9	22.6
				1160-1180	G <sub>s</sub>	23.7	7.0	23.3	23.4
				1240-1260	G <sub>s</sub>	20.9	6.7	15.5	16.6
				1100-1260	A‡	23.5	7.3	22.2	22.8
90	4.5	5	0.5	1100-1140	G <sub>s</sub>	24.4	6.4	29.4	25.3
				1150-1180	G <sub>s</sub>	23.0	6.5	27.4	24.4
				1100-1180	A‡	22.6	6.7	28.8	21.9
90	4.5	4	1.5	1100-1140	G <sub>s</sub>	23.6	6.3	26.5	22.9
				1180	G <sub>s</sub>	20.2	5.8	18.3	18.8
				1100-1180	A‡	22.3	7.2	24.2	20.6

\* t<sub>c</sub> = casting temperature.

† Shoulder type test piece 0.505 in. diam. × 2 in. gage length.

‡ W 600°/30 C<sub>f</sub> > 12 h.

## CU-SN-ZN-PB-AS, EFFECT OF ADDING PB TO ARSENICAL ADMIRALTY GUN METAL (41)

% composition*						t <sub>c</sub> , °C†	Trt‡	UTS	YP§	El <sub>a</sub>	BHN¶	Sch
Cu	Sn	Zn	As	Pb	Fe							
87.72	9.97	1.54	0.48	0.17	0.08	1210	G <sub>s</sub> .....	23.3	16.4	11.5	74	8.5
						1210	G <sub>m</sub> .....	26.9	16.7	5.0	91.0	9.0
88.23	10.04	0.98	.47	.18	.05	1220	Ml <sub>2</sub> G <sub>s</sub> .....	26.8	13.7	15.0	74	8.5
						1220	Ml <sub>2</sub> G <sub>m</sub> .....	24.7	17.5	5.0	92.0	9.0
87.30	10.05	1.16	.50	.86	.07	1220	G <sub>s</sub> .....	24.7	15.2	12.5	70	7.0
						1220	G <sub>m</sub> .....	24.7	18.0	4.5	87.6	8.0
87.84	10.00	0.72	.47	.91	.04	1210	Ml <sub>2</sub> G <sub>s</sub> .....	27.6	15.9	16.5	71	7.5
						1210	Ml <sub>2</sub> G <sub>m</sub> .....	25.0	16.8	5.5	91.0	8.0
86.58	10.04	1.33	.48	1.46	.06	1220	G <sub>s</sub> .....	25.0	15.4	15.0	66	6.0
						1220	G <sub>m</sub> .....	22.5	16.0	3.5	82.6	7.0
87.39	9.95	0.62	.48	1.48	.05	1210	Ml <sub>2</sub> G <sub>s</sub> .....	27.6	14.6	19.5	69	7.0
						1210	Ml <sub>2</sub> G <sub>m</sub> .....	21.9	15.4	3.5	85.0	7.0
86.23	10.12	1.42	.47	1.68	.06	1200	G <sub>s</sub> .....	24.9	14.8	10.5	69	7.0
						1200	G <sub>m</sub> .....	22.5	17.2	2.5	89.0	7.5
86.27	10.17	1.30	.49	1.67	.06	1230	Ml <sub>2</sub> G <sub>s</sub> .....	25.5	12.9	13.5	69	8.0
						1230	Ml <sub>2</sub> G <sub>m</sub> .....	23.3	15.1	3.0	89.0	8.0

\* All alloys contain traces of Sb and Ni.

† t<sub>c</sub> = casting temperature.‡ G<sub>s</sub> in green sand, all molds preheated. Castings 1 in. diam.

§ By dividers (extension = 0.01 in.).

|| Test piece diameter, 0.798 in.

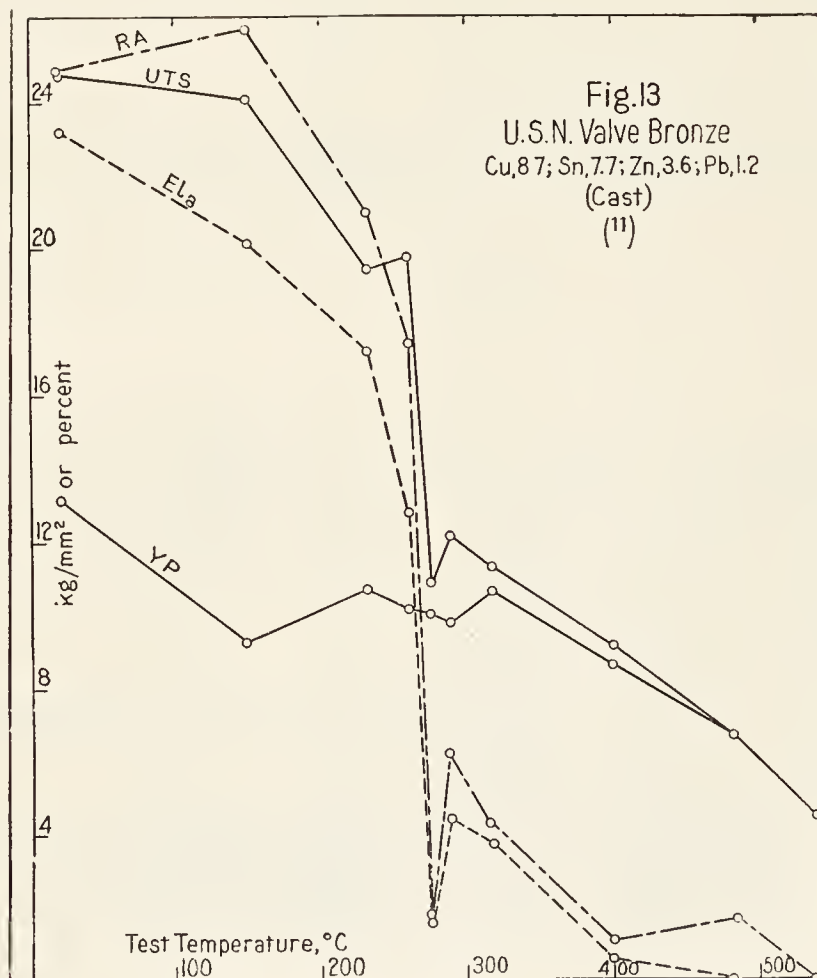
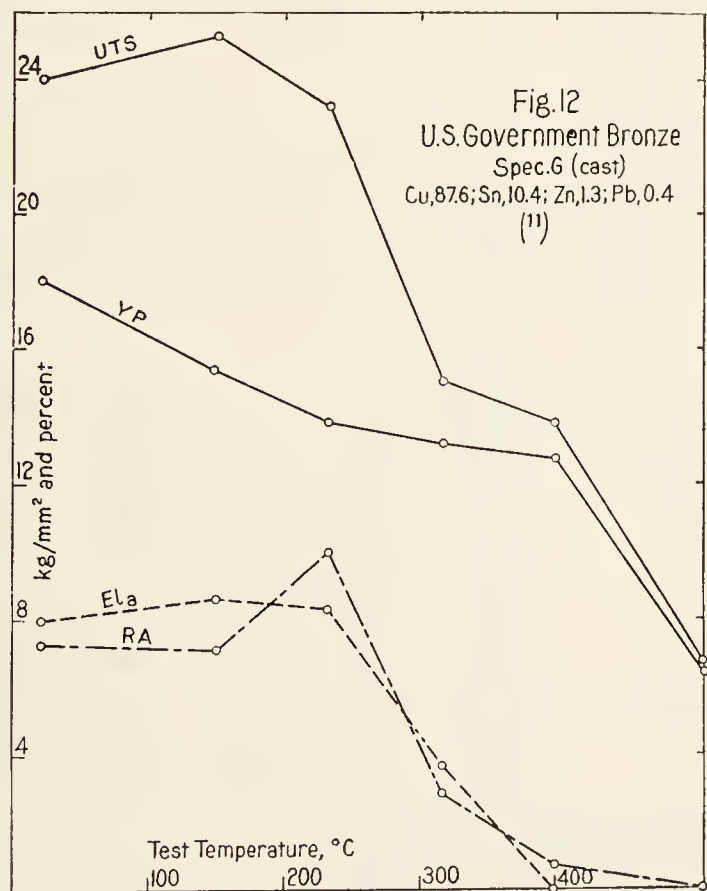
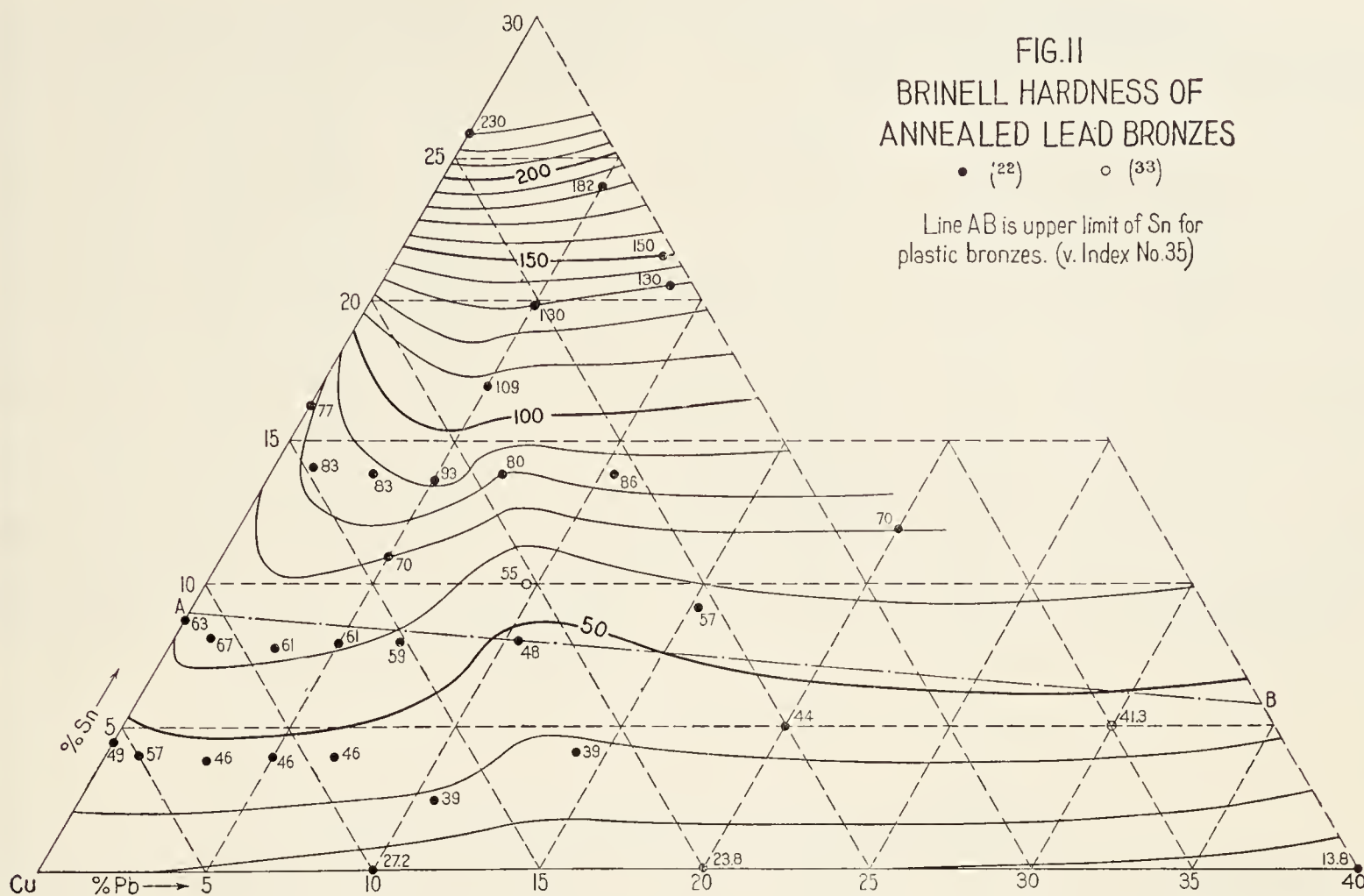
¶ 10 mm, 500 kg.



FIG. II  
BRINELL HARDNESS OF  
ANNEALED LEAD BRONZES

• (22)    ○ (33)

Line AB is upper limit of Sn for  
plastic bronzes. (v. Index No. 35)



CU-SN-ZN-SB, EFFECT OF ADDING SB TO ADMIRALTY GUN METAL (40)

% composition*							$t_c, ^\circ\text{C}^\dagger$	Trt $^\ddagger$	UTS	YP $^\S$	$El_a\parallel$	BHN $^\P$	ScH $^{**}$
Cu	Sn	Zn	Sb	Ni	Fe	Pb							
87.85	10.34	1.46	0.08	0.11	0.02	0.10	1240	G $_s$ .....	26.9	16.4	12.8	71	15.4
							1280	G $_m$ .....	23.8	16.1	2.4	81	14.8
89.44	9.55	0.55	.09	.11	.08	.11	1225	M $_2$ G $_s$ .....	26.0	14.6	17.0	77	14.7
							1250	M $_2$ G $_m$ .....	24.7	15.9	4.5	76	14.9
88.38	9.74	1.08	.50	.11	.02	.11	1220	G $_s$ .....	23.9	17.3	9.2	73	15.6
							1250	G $_m$ .....	23.8	16.7	2.0	82	15.5
88.38	9.73	0.93	.49	.12	.09	.07	1215	M $_2$ G $_s$ .....	26.0	15.1	13.8	79	15.8
							1240	M $_2$ G $_m$ .....	23.7	16.5	3.4	80	15.8
87.96	9.43	1.31	1.00	.10	.02	.08	1240	G $_s$ .....	23.8	16.9	6.8	82	16.5
							1270	G $_m$ .....	21.5	17.8	2.3	86	15.8
88.10	9.43	1.17	0.96	.10	.07	.10	1220	M $_2$ G $_s$ .....	21.9	14.7	6.9	81	16.5
							1245	M $_2$ G $_m$ .....	21.4	19.5	2.0	85	16.2
87.88	8.74	1.50	1.53	.09	.03	.07	1270	G $_s$ .....	18.9	14.1	3.6	79	16.7
							1310	G $_m$ .....	21.1	18.2	1.3	95	16.6
88.39	8.80	0.89	1.58	.10	.08	.07	1230	M $_2$ G $_s$ .....	18.3	14.9	3.8	81	16.6
							1270	M $_2$ G $_m$ .....	20.3	17.0	2.0	93	17.1

\* All alloys contain trace of As.

 $^\dagger t_c$  = casting temperature. $^\ddagger$  Bars cast 1 in. diam.  $\times$  15 in., sand cast ones being in green sand. Molds were vertical and preheated. $^\S$  By dividers. $\parallel$  Test piece diameter = 0.798 in. Each value mean from 2 test pieces. $^\P$  10 mm, 500 kg; mean of 6 determinations. $^{**}$  Each value mean of 14 determinations.

CU-SN-ZN-SB, EFFECT OF ADDING SB TO 86:9:5 RED BRONZE (21)

% composition*				Treatment	Part of casting	UTS	El	BHN†	Tw‡	Number of blows§
Cu	Sn	Zn	Sb							
86	9	5	0	Cast in green sand, 30 mm diam. × 160 mm long	Core	15.5	2.5	58	470	
					Shell	18.5	4.0			
86	9	5	0.1		Core	17.0	3.0	61	505	
					Shell	17.4	3.0			
85.25*	8.50*	5.62*	0.4*		Core	18.5	3.0	63	390	
Contains 0.2 % Pb					Shell	16.8	2.0			
86	9	5	0.5		Core	19.0	2.0	71	235	
					Shell	21.0	3.0			
86	9	5	1.0		Core	13.0	2.0	70	125	
					Shell	13.0	2.0			
86	9	5	3.0		Core	17.5	1.0	97	95	
					Shell	13.0	1.0			
86	9	5	0	Chill cast, then recast in green sand, 18 mm diam. × 180 mm long¶	Core only	24.0	7.5	65	500	230
86	9	5	0.1			25.5	7.0	73	450	325
Bal.	11.6*	4.0*	0.2*			23.3	4.5	78	540	230
Bal.	11.3*	4.5*	0.43*			24.3	7.0	74	465	470
Bal.	11.0*	4.7*	0.8*					80	280	42
86	9	5	1.0			25.3	5.5	73	340	35
86	9	5	3.0			16.5	<2	77		10
86	9	5	0	Chill cast, 18 mm diam. × 180 mm long**	Core only	20.5	4.0	81	330	3227††
86	9	5	0.1			24.5	4.5	77	350	2328††
86	9	5	0.3			20.5	2-3	75	550	830††
86	9	5	0.5				1.5	89		50††
86	9	5	1.0			22.3	2.5	84	360	60††
86	9	5	3.0			13.3		94	90	

\* By analysis, other values nominal.

 $^\dagger$  10 mm, 500 kg. $^\ddagger$  Twist in degrees. $^\S$  Energy of blow = 12.5 kg-cm. $\parallel$  Tensile specimens 8 mm diam., torsion specimens 7 mm diam.  $\times$  140 mm long. $^\P$  Tensile specimens 15 mm diam., torsion specimens 15 mm diam.  $\times$  100 mm long. $^{**}$  Tensile specimens 16 mm diam., torsion specimens 16 mm diam.  $\times$  120 mm long. $^\ddagger$  Bad break.



CU-SN-ZN-PB, EFFECT OF ADDING PB TO 86:9:5 RED BRONZE (20). See also Figs. 13 and 14

% composition				Treatment	Part of casting	UTS	El	BHN†	Tw‡	No. of blows§
Cu	Sn	Zn	Pb							
84.40*	8.63*	6.50*	0.17*	Cast in sand, 30 mm diam. × 160 mm long	Core	18.0	4.0	57.8	110**	
					Shell	19.6	6.0	62.7		
84.14	8.91	4.95	1.0		Core	13.8	2.7	60.5	220	
					Shell	17.0	4.0	63.0		
82.9*	8.65*	6.76*	1.71*		Core	15.2	1.5	62.5	270	
					Shell	18.0	3.0	61.5		
82.13*	8.17*	6.60*	2.84*		Core	17.0	5.2	63.0	285	
					Shell	19.2	6.5	65.5		
81.53*	8.54*	6.42*	3.52*		Core	14.2	2.2	59.0	235	
					Shell	18.0	5.0	60.5		
81.70	8.55	4.75	5.0		Core	15.0	3.0	65.0	320	
					Shell	19.5	5.2	62.0		
79.5*	8.18*	6.35*	5.89*		Core	14.3	2.0	62.5	185	
					Shell	16.8	3.3	61.5		
86	9	5	0	¶.....	Core only	22.0	7.8	77	200	3070
84.28	8.82	4.90	2			20.9	2.5	76	250	2380
82.56	8.64	4.80	4			14.9**	2.5	73	295	
80.84	8.46	4.70	6			13.5**	0.7	74	390	
Similar, Pb = ....	{	0.28*	2.22*	Chill cast, 18 mm diam. × 160 mm long††...	Core only	23.0	<3	82	260	360
						21.5	<3	89	325	122**
						14.3**	<3	81	285	160**
						16.4**	<3	83	340	34**
Similar, Pb = ....	{	0.49*	2.19*	Remelted and chill cast as above††.....	Core only	21.4	<3	83		
						20.0	<3	80		
						22.0	<3	84		
						19.8	<3	82		
Similar, Pb = .....	{	0	2	Melted third time and chill cast as above††...	Core only	23.1	<3	80		322
						21.4	<3	80		78**
						15.0**	<3	82		315
						17.1**	<3	81		260
Similar, Pb = .....	{	0	2	Chill cast, 18 mm diam. × 160 mm long††...	Core only	16.6	<3	87	295	53**
						22.8	<3	89	325	173
						21.8	<3	82	285	103
						20.0	<3	84	320	260

\* By analysis, other values nominal.

† 10 mm, 500 kg.

‡ Twist in degrees.

§ Energy of blow = 12.5 kg-cm.

|| Tensile specimens 8 mm diam., torsion specimens 8 × 5 × 40 mm.

¶ Tensile specimens 16 mm diam., torsion specimens 10 mm diam. × 80 mm long.

\*\* Bad break.

†† Tensile specimens 16 mm diam., torsion specimens 16 mm diam. × 120 mm long.

‡‡ Tensile specimens 16 mm diam., torsion specimens 16 mm diam. × 20 mm long.

CU-SN-ZN-PB-SB, EFFECT OF ADDING SB TO LEADED 86:9:5 RED BRONZE (21)

% composition*					Treatment	Part of casting	UTS	El	BHN†	Tw‡	Number of blows§
Cu	Sn	Zn	Pb	Sb							
86	9	5	2.0	0	Cast in green sand, 30 mm diam. × 160 mm long	Core	20.7	13	60	315	
						Shell	21.0	7.5			
86	9	5	2.0	0.1		Core	21.5	7	62	390	
						Shell	23.0	6.5			
84.55*	8.25*	4.74*	2.05*	0.4*		Core	21.5	13	70	395	
						Shell	22.5	10.5			
86	9	5	2.0	0.5		Core	17.0	2.5	65	355	
						Shell	19.3	4			
86	9	5	2.0	1.0		Core	17.5	2.5	70	270	
						Shell	19.0	4			
82.20*	8.00*	4.58*	2.08*	2.90*		Core	16.1	3.0	80	150	
						Shell	16.0	1.5			

Cu-Sn-Zn-Pb-Sb, EFFECT OF ADDING Sb TO LEADED 86:9:5 RED BRONZE (21).—(Continued)

% composition*					Treatment	Part of casting	UTS	El	BHN†	Tw‡	Number of blows§
Cu	Sn	Zn	Pb	Sb							
Bal.	8.7	5	2.0	0	Cast in dry sand, 18 mm diam. × 160 mm long¶	Core only	16.2	4.0	62.5	550	35-45
			2.1*	0.2*			19.0	4.0	67	620	75
			2.1*	0.4*			18.7	3.0	59	470	145-220
			2.0	0.75*			18.7	2.0	72.5	515	22
			2.0	3.0			13.5	1.0	72.5	60	1
86	9	5	5.0	0	Cast in dry sand, 18 mm diam. × 160 mm long**	Core only	21.7	7.6	65	570	383
			5.5*	0.2*			22.2	4.7	64	570	584
			5.5*	0.42*			18.4	3.5	68.5	450	163-455
			5.5*	0.74*			18.4	1.8	74	340	143
			5.0	3.0			17.6	1.8	70	195	54

\* By analysis, other values nominal.    ¶ Tensile specimens 8 mm diam., torsion specimens 7 mm diam. × 40 mm long.  
† 10 mm, 500 kg.    ¶ Tensile specimens 15 mm diam., torsion specimens 16 mm diam. × 160 mm long.  
‡ Twist in degrees.    \*\* Tensile specimens 16 mm diam., torsion specimens 16 mm diam. × 120 mm long.  
§ Energy of blow = 12.5 kg-cm.

IMPACT STRENGTH

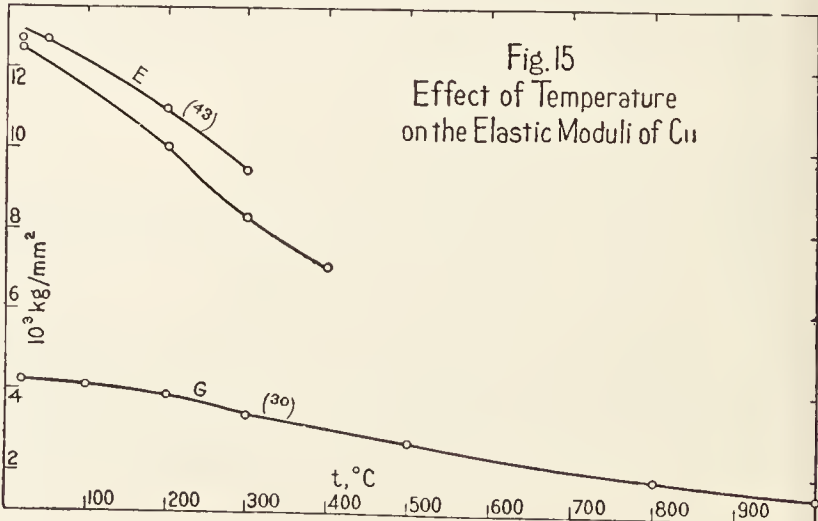
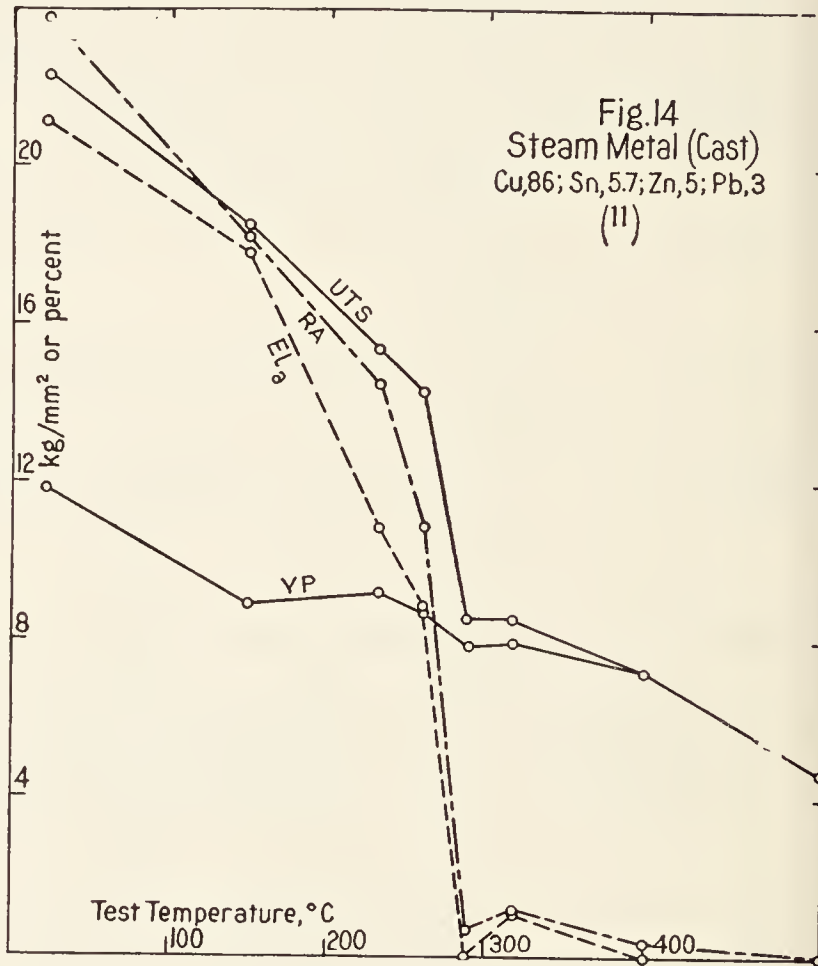
% composition			Description and treatment	IS, kg-m	Machine	Test piece*	Lit.
Cu	Sn	Zn					
99.9			Tested at.....	$\left. \begin{array}{l} 20^{\circ} \quad 20.6 \uparrow \\ -20^{\circ} \quad 18.7 \uparrow \\ -80^{\circ} \quad 20.6 \uparrow \\ -182^{\circ} \quad 20.1 \uparrow \end{array} \right\}$	Guillery	A	(24)
99.8			Fire box plates				
			Longitudinal.....	10.4-19	Fremont	B	(9)
			Transverse.....	5.3-6.6			
84	16		A 650° or 650° Q.....	†			
			Sand cast at...	$\left\{ \begin{array}{l} 1240^{\circ} \quad 2.9 \\ 1175^{\circ} \quad 3.5 \\ 1140^{\circ} \quad 1.95 \\ \leq 1090^{\circ} \quad 1.2-1.4 \end{array} \right\}$	Izod	C	
			Cast, test- ed at	$\left\{ \begin{array}{l} -80 \text{ to } 375^{\circ} \quad 0.21 \\ 470^{\circ} \quad 0.35 \end{array} \right\}$	Charpy	D	
94.5	4	1.5	Annealed, tested at	$\left\{ \begin{array}{l} -80^{\circ} \quad 0.7 \\ 350-850^{\circ} \quad 0.1 \end{array} \right\}$	Charpy	D	
88	10	2	Casting temperature				
			Diameter				
			1100-1200°	$\left\{ \begin{array}{l} 0.5 \text{ in.} \quad 0.7-0.8 \\ 1.0 \text{ in.} \quad 1.4-1.5 \end{array} \right\}$			
			1100°	2.0 in. 0.4-0.8	Izod	C	
			1100°	2.0 in. 1.9-2.5			
			1200°	2.0 in. 1.4-1.7			

\* A = Mesnager specimen; B = bars 10 mm<sup>2</sup> cross-section, with saw cut, 3 mm deep; C = standard B. E. S. A. specimen; D = small Charpy test piece.  
† Unbroken.

SPECIFIC GRAVITY\*

% composition				Trt	d <sub>4</sub> <sup>20</sup>	Lit.
Cu	Sn	Pb	Zn			
100				D, A 500°.....	8.89	(13)
99.6				G.....	8.85	(14)
				R <sub>d</sub> , 40 %.....	8.89	
				A 500°.....	8.90	
90	10			G.....	8.78	(14)
80	20			G.....	8.81	(14)
70	30			G.....	8.84	(14)
95	4.9	P, 0.1		R.....	8.6	(14)
89	11	P, 0.3		G.....	8.5	(56)
80	10	10†		G.....	9.1	(14)
88	10		2	G <sub>s</sub> .....	8.4-8.8	(29)
				G <sub>m</sub> .....	8.6	
88	8		4	G.....	8.5	(14)
80	10		10	G <sub>s</sub> .....	8.85	(39.1)

\* v. also Fig. 2 and 16 and pp. 456, 554.  
† Phosphor bronze.

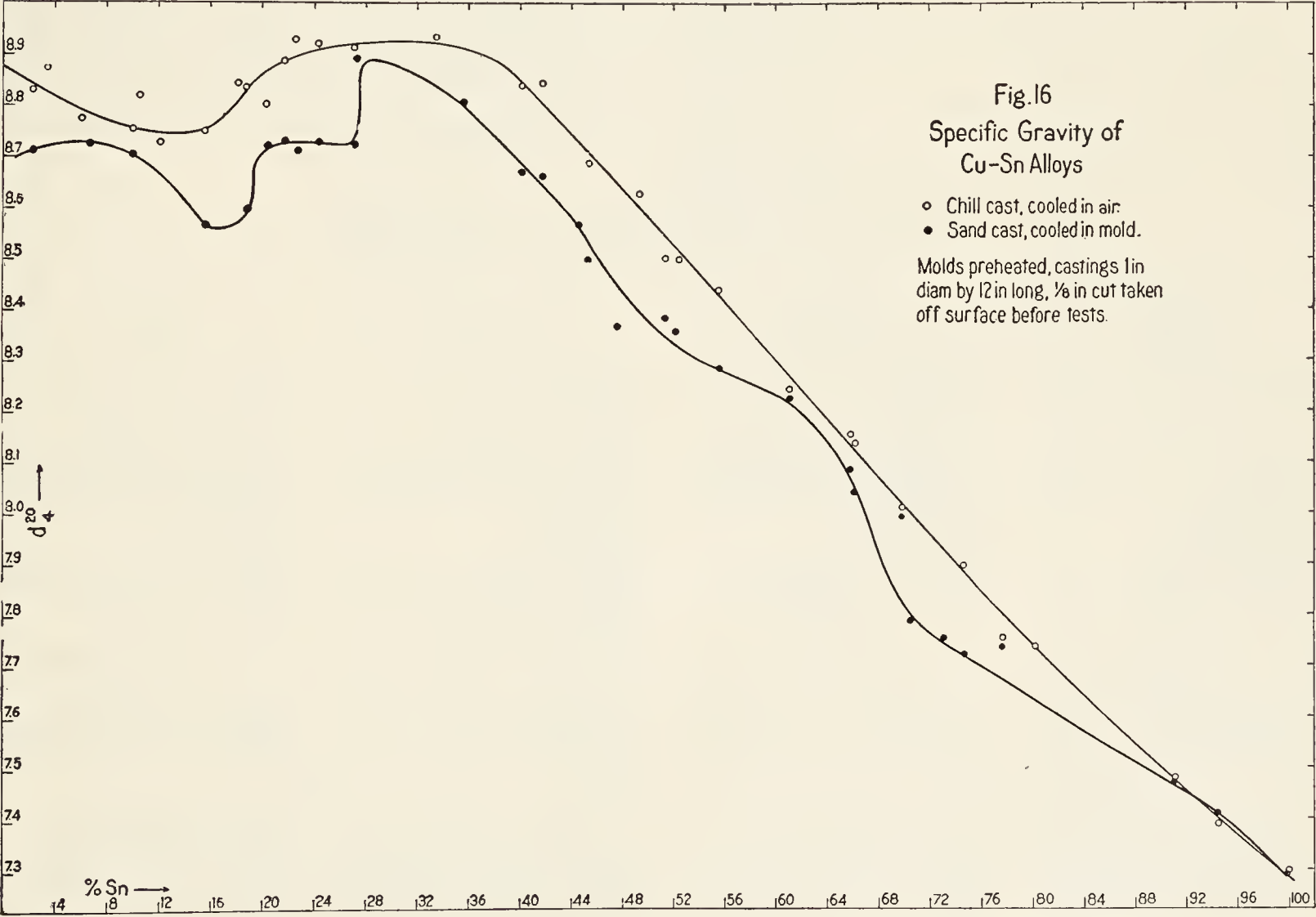




ELASTIC PROPERTIES  
See also Fig. 15

% composition				Description and treatment	10 <sup>-3</sup> E	10 <sup>-3</sup> G	10 <sup>-3</sup> K	λ	Lit.
Cu	Sn	Pb	Zn						
100 Nominal*				Electrolytic Cu.....	12.1-12.3				(13)
				Cast.....	10.85			0.60	(57)
				Drawn.....	12.65	3.96			(44)
				Annealed.....	13.19	13.2			(44)
				Hard drawn.....	9.8				(7)
						4.24	12.0	0.33	(30, 57)
93	7			Cast....	9.8	3.7			(30, 50)
88	12			Cast.....	10.6	4.06			(57)
89	4	Ni, 4	3		10.5				(12)
88	5	Ni, 5	2		12.2				(12)
88	10	2		Gov. bronze specification.....	{ G 8.9 Pc2 8.8				(17)
86.5	10.2	0.1	3.3		9.1				(31)
85.4	12.6	0.6	1.0†		10.4				(31)

\* For Cu:  $E = E_0 (1 - 3.59 \times 10^{-4} t)$  at ordinary temperatures (51).  $G = G_0 (1 + 2.3 \times 10^{-4} t)$  from 0 to 15° (13).  $E_{0^{\circ}\text{abs.}}/E_{0^{\circ}\text{C}} = 1.37$  (32).  
† Phosphor bronze.



MOLD SHRINKAGE; *v. also* p. 475

% composition				Trt	$-100 \frac{\Delta l}{l}$	Lit.
Cu	Sn	Pb	Zn			
94.7	5.1			G.....	1.66	(58)
92	8*			G.....	1.54	(37)
89.7	10.2			G.....	1.44	(58)
89	11†			G.....	1.04	(56)
80.7	19.1			G.....	1.52	(58)
85-70	10-5	5.25		G.....	2.08	(6)
88.8	9.7		1.6	G.....	1.47	(58)
88	10		2	G.....	1.50	(37)
				G.....	1.08	(39.1)
80	10		10	G.....	1.34	(37)
				G.....	1.03	(39.1)
86.7	9.8	1.4	2	G.....	1.47	(58)

\* Phosphor bronze.

† Stone's English gear bronze, contains 0.3% P.

## THERMAL CONDUCTIVITY

% composition			Treatment	$t, ^\circ\text{C}$	$k$
Cu	Sn	As			
100			Annealed (electrolytic Cu)...	96 625	3.77 3.52
99.6		0.39	Annealed.....	90 420	2.14 2.22
88	12		As cast (phosphor bronze)....	94.5	0.539
		Zn		431	0.728
88	10	2	As cast (Gov. bronze).....	83.5 418.5	0.573 0.720
86	9	5	As cast.....	88 418.5	0.715 0.808

## LITERATURE

(For a key to the periodicals see end of volume)

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## PROPERTIES OF ALUMINUM BRONZES

W. M. CORSE

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## Cu-Al

## PROPERTIES OF Cu-Al, AL &gt; 15%

The alloys of this series between 15 and 90% Al do not appear to be of any technical value. From 15 to 18% Al they are very hard and very brittle. From 20 to 65% Al they diminish in hardness, but are so brittle they can be powdered easily in a mortar, which makes them of some use in weighing out quantities to make up alloys. This excessive brittleness ceases at about 67% Al (3).

TABLE 1.—AVERAGE PROPERTIES (13)

% Cu	% Al	Treatment	UTS	YP	El	RA	BHN	$d_{40}^2$
95	5	R <sub>d</sub> sheet.....	70		10			8.18
		R <sub>s</sub> sheet.....	39		75			
92	8	R <sub>d</sub> sheet.....	91		4			7.80
		R <sub>s</sub> sheet.....	42		60			
90	10	G <sub>s</sub> .....	46-53	14-21	20	21	90-100	DL <sub>C</sub> = 13-14
		Wk <sub>d</sub> rod.....	88		5			
		Wk <sub>s</sub> rod.....	55		36			

TABLE 2.—TENSILE PROPERTIES\* (AL &lt; 14%) (3).—(Continued)

Treatment†	10 × UTS	10 × YP‡	Elₐ§	RA
Cu, 99.86; Al, 0.10; Si, 0.000; Fe, 0.000				
G <sub>s</sub> .....	181	60	46.0	
G <sub>s</sub> , W 800° C <sub>s</sub> .....	179	66	40.0	
G <sub>s</sub> , W 900° Q <sub>w</sub> .....	168	46	40.0	
G <sub>m</sub> .....	182	65	46.0	
G <sub>m</sub> , W 800° C <sub>s</sub> .....	174	77	44.0	
G <sub>m</sub> , W 800° Q <sub>w</sub> .....	178	63	47.5	
R <sub>h</sub> 1 $\frac{1}{16}$ in. diam.....	228	109	65.5	90.7
Same, W { 800° C <sub>s</sub> .....	223	69	62.0	92.5
	221	69	65.0	91.8
Cu, 98.95; Al, 1.06; Si, 0.010; Fe(Tr.)				
G <sub>s</sub> .....	211	47	52.0	
G <sub>s</sub> , W 800° C <sub>s</sub> .....	203	50	46.0	
G <sub>m</sub> .....	186	82	53.0	
G <sub>m</sub> , W 800° C <sub>s</sub> .....	203	71	57.0	
G <sub>m</sub> , W 800° Q <sub>w</sub> .....	199		53.5	
R <sub>h</sub> 1 $\frac{1}{4}$ in. diam.....	247	106	59.0	90.9
R <sub>h</sub> 1 $\frac{3}{16}$ in. diam.....	250	109	61.0	88.6
Same, W { 800° C <sub>s</sub> .....	240	69	67.0	91.9
	243	68	63.5	90.8
D <sub>c</sub> 1 $\frac{3}{16}$ in. diam.....	285	273	42.0	88.8
Cu, 97.88; Al, 2.10; Si, 0.018; Fe, 0.004				
G <sub>s</sub> .....	213	54	53.5	
G <sub>s</sub> , W 800° C <sub>s</sub> .....	221	55	46.5	
G <sub>s</sub> , W 800° Q <sub>w</sub> .....	221	68	47.0	
G <sub>m</sub> .....	216	71	54.5	
G <sub>m</sub> , W 800° C <sub>s</sub> .....	219	76	56.0	
G <sub>m</sub> , W 800° Q <sub>w</sub> .....	219	68	55.0	
R <sub>h</sub> 1 $\frac{1}{4}$ in. diam.....	271	101	61.0	90.0
R <sub>h</sub> 1 $\frac{3}{16}$ in. diam.....	275	136	56.5	89.7
Same, W { 800° C <sub>s</sub> .....	262	69	66.0	90.0
	264	68	63.5	88.8
Cu, 96.98; Al, 2.99; Si, 0.024; Fe, 0.008				
G <sub>s</sub> .....	229	60	60.0	
G <sub>s</sub> , W 800° C <sub>s</sub> .....	233	58	60.5	
G <sub>s</sub> , W 800° Q <sub>w</sub> .....	233	77	58.5	
G <sub>m</sub> .....	217	107	60.0	
G <sub>m</sub> , W 800° C <sub>s</sub> .....	230	69	73.0	
G <sub>m</sub> , W 800° Q <sub>w</sub> .....	235	74	53.0	
R <sub>h</sub> 1 $\frac{1}{4}$ in. diam.....	299	124	67.0	88.8
R <sub>h</sub> 1 $\frac{3}{16}$ in. diam.....	312	183	57.3	86.1
Same, W { 800° C <sub>s</sub> .....	284	76	73.0	90.0
	285	87	69.0	88.8
	292	109	66.0	89.8
	311	91	82.5	83.6
D <sub>c</sub> 1 $\frac{3}{16}$ in. diam.....	351	331	44.0	86.1
Cu, 95.92; Al, 4.05; Si, 0.019; Fe, 0.011				
G <sub>s</sub> .....	263	55	83.0	
G <sub>s</sub> , W 800° C <sub>s</sub> .....	268	62	68.5	
G <sub>s</sub> , W 800° Q <sub>w</sub> .....	260	79	60.0	
G <sub>m</sub> .....	269	77	82.0	
G <sub>m</sub> , W 800° C <sub>s</sub> .....	258	68	89.0	
G <sub>m</sub> , W 800° Q <sub>w</sub> .....	279	80	81.3	
R <sub>h</sub> 1 $\frac{1}{4}$ in. diam.....	346	115	71.0	81.8
R <sub>h</sub> 1 $\frac{3}{16}$ in. diam.....	375	178	67.0	83.3
Same, W { 800° C <sub>s</sub> .....	339	96	73.0	85.7
	335	101	79.0	84.8

TABLE 2.—TENSILE PROPERTIES\* (AL &lt; 14%) (3).—(Continued)

Treatment†	10 × UTS	10 × YP‡	Elₐ§	RA
Cu, 94.90; Al, 5.07; Si, 0.018; Fe, 0.006				
G <sub>s</sub> .....	285	68	75.0	
G <sub>s</sub> , W 800° C <sub>s</sub> .....	296	57	65.5	
G <sub>s</sub> , W 800° Q <sub>w</sub> .....	293	79	66.5	
G <sub>m</sub> .....	285	112	60.5	
G <sub>m</sub> , W 800° C <sub>s</sub> .....	284	80	61.0	
G <sub>m</sub> , W 800° Q <sub>w</sub> .....	301	90	80.0	
R <sub>h</sub> 1 $\frac{1}{4}$ in. diam.....	387	107	79.0	77.0
R <sub>h</sub> 1 $\frac{3}{16}$ in. diam.....	416	180	69.2	77.8
Same, W { 800° C <sub>s</sub> .....	373	82	79.0	82.0
	371	98	83.0	78.8
D <sub>c</sub> 1 $\frac{3}{16}$ in. diam.....	479	375		
Cu, 94.20; Al, 5.76; Si, 0.027; Fe, 0.010				
G <sub>s</sub> .....	280	76	67.0	
G <sub>s</sub> , W 800° C <sub>s</sub> .....	306	60	65.0	
G <sub>s</sub> , W 800° Q <sub>w</sub> .....	285	85	52.5	
G <sub>m</sub> .....	296	95	61.0	
G <sub>m</sub> , W 800° C <sub>s</sub> .....	307	88	74.0	
G <sub>m</sub> , W 800° Q <sub>w</sub> .....	323	129	49.0	
R <sub>h</sub> 1 $\frac{3}{16}$ in. diam.....	448	186	74.2	76.9
Same, W { 800° C <sub>s</sub> .....	419	124	77.5	71.0
	393	109	84.5	75.6
	429	148	77.0	75.0
	373	95	86.0	70.0
Cu, 93.23; Al, 6.73; Si, 0.026; Fe, 0.016				
G <sub>s</sub> .....	294	76		
G <sub>s</sub> , W 800° C <sub>s</sub> .....	297	76	64.0	
G <sub>s</sub> , W 800° Q <sub>w</sub> .....	313	99	51.0	
G <sub>m</sub> .....	315		69.0	
G <sub>m</sub> , W 800° Q <sub>w</sub> .....	298	82	42.0	
R <sub>h</sub> 1 $\frac{1}{4}$ in. diam.....	412	118	82.0	75.4
R <sub>h</sub> 1 $\frac{3}{16}$ in. diam.....	455	164	71.0	75.0
Same, W { 800° C <sub>s</sub> .....	418	112	82.5	73.5
	401	117	83.0	72.0
Cu, 92.61; Al, 7.35; Si, 0.027; Fe, 0.017				
G <sub>s</sub> .....	336	104	71.0	
G <sub>s</sub> , W 800° C <sub>s</sub> .....	317	93	81.0	
G <sub>s</sub> , W 800° Q <sub>w</sub> .....	315	106	70.0	
G <sub>m</sub> .....	340		84.0	
G <sub>m</sub> , W 800° C <sub>s</sub> .....	318	95	80.0	
G <sub>m</sub> , W 800° Q <sub>w</sub> .....	312	115	79.0	
R <sub>h</sub> 1 $\frac{1}{4}$ in. diam.....	432	147	80.0	75.3
R <sub>h</sub> 1 $\frac{3}{16}$ in. diam.....	468	167	72.5	74.3
Same, W { 800° C <sub>s</sub> .....	401	117	80.5	74.8
	402	126	82.0	74.8
	376	112	92.0	72.0
D <sub>c</sub> 1 $\frac{3}{16}$ in. diam.....	495	388	48.0	58.8
Cu, 91.85; Al, 8.12; Si, 0.012; Fe, 0.012				
G <sub>s</sub> .....	393	121	58.0	
G <sub>s</sub> , W 800° C <sub>s</sub> .....	349	109	69.0	
G <sub>s</sub> , W 800° Q <sub>w</sub> .....	410	124	62.5	
G <sub>m</sub> .....	433	153	62.0	
G <sub>m</sub> , W 800° C <sub>s</sub> .....	350	115	59.0	
G <sub>m</sub> , W 800° Q <sub>w</sub> .....	393	132	61.0	
R <sub>h</sub> 1 $\frac{1}{4}$ in. diam.....	487	154	70.0	64.5
R <sub>h</sub> 1 $\frac{3}{16}$ in. diam.....	524	205	51.5	60.4
Same, W { 800° C <sub>s</sub> .....	430	128	80.0	70.0
	448	118	74.0	69.3



TABLE 2.—TENSILE PROPERTIES\* (AL &lt; 14%) (3).—(Continued)

Treatment†	10 × UTS	10 × YP‡	El <sub>a</sub> §	RA	
Cu, 91.28; Al, 8.67; Si, 0.032; Fe, 0.021					
G <sub>s</sub> .....	443	154	48.0		
G <sub>s</sub> , W 800° C <sub>s</sub> .....	370	139	48.0		
G <sub>s</sub> , W 800° Q <sub>w</sub> .....	484	184	35.0		
G <sub>m</sub> .....	485		55.0		
G <sub>m</sub> , W 800° C <sub>s</sub> .....	427	139	63.0		
G <sub>m</sub> , W 800° Q <sub>w</sub> .....	470	153	54.0		
R <sub>h</sub> 1 $\frac{3}{16}$ in. diam.....	578	175	38.0	50.7	
Same, W {	800° C <sub>s</sub> .....	473	180	65.0	64.9
	600° Q <sub>w</sub> .....	596		48.0	61.2
	700° Q <sub>w</sub> .....	554		54.0	66.7
	800° Q <sub>w</sub> .....	551	199	51.0	59.6
	900° Q <sub>w</sub> .....	618		40.0	51.7
Cu, 90.58; Al, 9.38; Si, 0.021; Fe, 0.019					
G <sub>s</sub> .....	479	153	36.3	47.2	
G <sub>s</sub> , W 900° C <sub>s</sub> .....	369	169	17.3	31.9	
G <sub>s</sub> , W 800° Q <sub>w</sub> .....	601	328	9.5	20.0	
G <sub>m</sub> .....	536	165	43.5	50.0	
G <sub>m</sub> , W 800° C <sub>s</sub> .....	433	178	27.0	30.5	
G <sub>m</sub> , W 800° Q <sub>w</sub> .....	561	295	28.0	46.3	
R <sub>h</sub> 1 $\frac{1}{4}$ in. diam.....	589	233	40.0	41.4	
R <sub>h</sub> 1 $\frac{3}{16}$ in. diam.....	599	279	34.0	33.6	
Same, W {	600° Q <sub>w</sub> .....	614	251	38.5	50.8
	700° Q <sub>w</sub> .....	607	262	35.5	42.9
	800° Q <sub>w</sub> .....	615	301	32.0	42.7
	900° Q <sub>w</sub> .....	668	292	25.5	39.3
D <sub>c</sub> 1 $\frac{3}{16}$ in. diam.....	612	457	32.0	46.3	
Cu, 90.06; Al, 9.90; Si, 0.027; Fe, 0.017					
G <sub>s</sub> .....	499	178	21.7		
G <sub>s</sub> , W 800° C <sub>s</sub> .....		210			
G <sub>s</sub> , W 800° Q <sub>w</sub> .....	788	353	3.0		
G <sub>m</sub> .....	582	195	30.5		
G <sub>m</sub> , W 800° C <sub>s</sub> .....	416	260	5.0		
G <sub>m</sub> , W 700° Q <sub>w</sub> .....	601	200	25.0	32.0	
G <sub>m</sub> , W 800° Q <sub>w</sub> .....	607	217	22.0	28.5	
	608	279	22.0		
G <sub>m</sub> , W 900° Q <sub>w</sub> .....	709	577	3.0	10.8	
R <sub>h</sub> 1 $\frac{1}{4}$ in. diam.....	552	214	31.5	30.5	
R <sub>h</sub> 1 $\frac{3}{16}$ in. diam.....	600	233	28.8	30.8	
Same, W {	800° C <sub>s</sub> .....	449	247	6.5	10.2
	300° C <sub>f</sub> .....	600	230	27.0	33.1
	400° C <sub>f</sub> .....	499	369	2.5	2.9
	500° C <sub>f</sub> .....	537	323	9.5	13.1
	600° C <sub>f</sub> .....	500	247	9.0	14.5
	700° C <sub>f</sub> .....	502	238	9.0	11.3
	800° C <sub>f</sub> .....	413	200	13.5	21.6
	900° C <sub>f</sub> .....	346	210	6.0	8.8
	600° Q <sub>w</sub> .....	608	268	29.0	35.7
	700° Q <sub>w</sub> .....	585	246	20.5	27.0
	800° Q <sub>w</sub> .....	717	413	11.0	16.8
	900° Q <sub>w</sub> .....	854	659	2.5	7.0
R <sub>h</sub> ¶, W {	600° Q <sub>w</sub> .....	602	268	22.2	30.0
	700° Q <sub>w</sub> .....	626	285	15.4	20.6
	800° Q <sub>w</sub> .....	686	511	7.0	14.3
	900° Q <sub>w</sub> .....	812	627	3.0	4.8
D <sub>c</sub> 1 $\frac{3}{16}$ in. diam.....	692	637	13.0	22.2	

TABLE 2.—TENSILE PROPERTIES\* (AL &lt; 14%) (3).—(Continued)

Treatment†	10 × UTS	10 × YP‡	El <sub>a</sub> §	RA
Cu, 89.17; Al, 10.78; Si, 0.031; Fe, 0.015				
G <sub>s</sub> .....	465	222	9.0	
G <sub>s</sub> , W 800° C <sub>s</sub> .....	460	425	2.0	
G <sub>s</sub> , W 800° Q <sub>w</sub> .....	559	468	2.5	
G <sub>m</sub> .....	579	266	9.0	
G <sub>m</sub> , W 800° C <sub>s</sub> .....	453	372	0.0	
G <sub>m</sub> , W 800° Q <sub>w</sub> .....	510	421	3.0	
R <sub>h</sub> 1½ in. diam.....	551	284	12.5	12.1
R <sub>h</sub> 1⅜ in. diam.....	609	243	14.0	18.6
Same, W {	800° C <sub>s</sub> .....	479	1.5	4.0
	800° Q <sub>w</sub> .....	569	5.0	13.3
Cu, 88.32; Al, 11.73; Si, 0.028; Fe, 0.010				
G <sub>s</sub> .....	401	221	5.0	
G <sub>s</sub> , W 800° C <sub>s</sub> .....	305	305	1.0	
G <sub>s</sub> , W 800° Q <sub>w</sub> .....	391	265	5.0	
G <sub>m</sub> .....	482	233	6.0	
G <sub>m</sub> , W 800° Q <sub>w</sub> .....	395	197	5.0	
R <sub>h</sub> 1½ in. diam.....	506	299	5.5	4.2
R <sub>h</sub> 1⅜ in. diam.....	533	199	8.5	15.4
Same, W {	800° C <sub>s</sub> .....	385	1.0	2.7
	800° Q <sub>w</sub> .....	401	189	6.0
Cu, 86.92; Al, 13.02; Si, 0.043; Fe, 0.013				
G <sub>s</sub> .....	311	311	1.0	
G <sub>s</sub> , W 800° C <sub>s</sub> .....	249	249	2.0	
G <sub>s</sub> , W 800° Q <sub>w</sub> .....	365	220	4.5	
G <sub>m</sub> .....	395	395	0.0	
G <sub>m</sub> , W 800° C <sub>s</sub> .....	260	260	0.0	
G <sub>m</sub> , W 800° Q <sub>w</sub> .....	409	186	4.0	
R <sub>h</sub> 1⅜ in. diam.....	585		2.0	1.9

\* The alloys in this table were made up of 99.98–99.99 % pure Cu and 99.70 % pure Al. A specimen of 99.96 % pure Cu, R<sub>h</sub> to 1½ in. and C<sub>s</sub> from 800°C had the following properties: UTS = 22.3, YP = 7.9, El = 56.0, RA = 67.8. The ductility is greatly increased by adding only 0.1 % Al. Additional properties of the commercially important Al bronzes are given in the following tables.

† Treatments in detail are: G<sub>s</sub>, in small test piece size; G<sub>m</sub>, in 1 in. diam. size and machined down. The mechanically worked specimens are from a G<sub>m</sub> 20 × 3 in. diam. ingot. This was machined to 2½ in. diam., W 800° R to 1½ in. diam. One portion R<sub>h</sub> to 1½ in. diam.

‡ By dividers.

§ Test piece 0.564 in. diam., 2 in. gage length except where noted.

|| Broke in threads, fracture coarsely crystalline.

¶ These specimens were machined to test piece size (½ in. diam.) before heat treatment.

TABLE 3.—TENSILE PROPERTIES AT HIGH TEMPERATURES

t, °C	Cu, 95; Al, 5 Cast (2, 15)				Cu, 90; Al, 10 Cast (2, 15)		
	UTS	YP	Elₐ	RA	UTS	Elₐ	RA
20	24.7	19.5	56.3	46.9	29.1	9.4	13.1
150	22.7		78.1	31.4			
230	25.2	11.0	65.7	61.7	29.7	12.5	4.8
315	17.3	12.9	45.3	38.4	27.0	11.5	11.6
400	4.5	4.5	0.0	0.0	18.8	1.6	2.9
510					18.2	3.1	6.7
540	4.4	4.4	0.0	0.0			

TABLE 3.—TENSILE PROPERTIES AT HIGH TEMPERATURES.—  
(Continued)

$t, ^\circ\text{C}$	Cu, 93; Al, 6.7 ( $R_h$ )* (23; cf. 27)		Cu, 90; Al, 10 ( $R_h$ )* (23); cf. (27)	
	UTS†	$El_a$	UTS†	$El_a$
20	45.5	71.0	60.0	28.8
200			57.4	35.0–38.0
250	37.3	25.5–29.0	50.0	21.5
300	32.6	24.5–25.0	52.6	18.5–40.0
350	30.3	17.5	51.7	27.5–33.0
400	28.2	14.0–18.0	37.8	29.0–48.0
450	21.0	9.0–10.0	35.1	30.5–32.5
500	17.2	14.0	19.1	42.0–92.5
550			14.3	10.2

\* For exact composition v. Table 2. Specimens hot rolled to  $1\frac{3}{16}$  in. diam.  
† Mean values.

TABLE 4.—BRINELL HARDNESS AT HIGH TEMPERATURES (12)

% Al	Impurities	$t, ^\circ\text{C}$									
		20	250	350	450	550	650	750	850	950	
3.82	Si, 0.09.....	39.4	33.8	31.4	31.4	31.4	22.4	17.6	13.2		
4.07	Si, 0.08.....	38.1	29.6	28.4	29.2	29	27.4	17.2			
6.75	Sn, 0.27.....	34.9	34.4	31.4	31.4	31.8	29.7	16.5	8.2		
9.76	Fe, 0.22.....	76.7	71.1	65.1	61	40.5	25.4	14.2	7	2.9	

TABLE 5.—BRINELL HARDNESS (3)

% Al	Trt*	Load, kg			UTS
		1034	3000		
0.10	$R_h$ .....	78	66		22.8
2.99	$R_h$ .....	109	102		31.2
5.07	$R_h$ .....	113	124		41.6
7.35	$R_h$ .....	123	134		46.8
9.90	$R_h$ .....	180	210		60.0
11.73	$R_h$ .....	213	269		53.3
13.02	$R_h$ .....	332	349		58.5
13.50	$G_s$ .....	372	437		
15.38	$G_s$ .....	411	539		

\* Tests, except last two, made on  $1\frac{3}{16}$  in. diam. hot rolled bars. Ball diam. = 9.516 mm.

TABLE 6.—TORSIONAL STRENGTH\* (3)

% Al	USSC	TMR	UTS	Twist, °/cm
0.00	19.8	26.4		359
0.10	25.2	33.7	22.4	681
1.06	26.0	34.7	24.7	570
2.10	27.2	36.3	27.1	506
4.05	31.0	41.4	34.6	304
6.73	36.4	48.6	41.2	213
7.35	37.2	49.6	43.2	180
9.90	36.8	49.3	55.2	31
11.73	39.5	52.7	50.6	6.7

\* Specimens machined from  $1\frac{1}{4}$  in. bar, hot rolled to 0.624 in. diam.  $\times$  3.0 in. long, except for 2.1 % Al which is 2.8 in. long.

TABLE 7.—DYNAMIC TESTS (3)

% Al	No. of bends*		IS† (Izod)	Condition after Izod test
	$\frac{3}{8}$ in. diam.	$\frac{3}{8}$ in. sq.		
0.10	287	443	1.23	Unbroken
2.99	332	456	1.70	
5.07	632	814	1.96	
7.35	1395	1373	2.13	

TABLE 7.—DYNAMIC TESTS (3).—(Continued)

% Al	No. of bends*		IS† (Izod)	Condition after Izod test
	$\frac{3}{8}$ in. diam.	$\frac{3}{8}$ in. sq.		
9.90	657	783	0.62	Broken
11.73			0.54	
13.02			0.12	

\* Tests made on Arnold machine, bars 5.5 in. long.

† Tests bars  $2 \times \frac{3}{8} \times \frac{3}{16}$  in. For both tests, bars were machined from hot rolled  $1\frac{3}{16}$  in. diam. bars.

TABLE 8.—SPECIFIC GRAVITY OF AL-BRONZES (3)

% Al	Trt	$G_s$	$G_m$	$R^*$
0.10		8.90	8.90	8.92
1.06		8.79	8.77	8.78
2.10		8.54	8.61	8.62
2.99		8.44	8.47	8.47
4.05		8.29	8.31	8.31
5.07		8.16	8.18	8.18
5.76		8.04	8.07	8.07
6.73		7.94	7.96	7.95
7.35		7.85	7.86	7.85
8.12		7.79	7.78	7.78
8.67		7.73	7.69	7.69
9.38		7.64	7.61	7.61
9.90		7.60	7.56	7.56
10.78		7.45	7.45	7.45
11.73		7.19	7.34	7.35
13.02		6.98	7.23	7.23

\* Rolled to  $1\frac{3}{16}$  in. diam.

TABLE 9.—COMPRESSIBILITY AND SPECIFIC GRAVITY OF CU-AL ALLOYS (14)

% Al ca.	$t, ^\circ\text{C}$	$10^8 \chi^*$	$t, ^\circ\text{C}$	$d_4^{20}$
5	16	103	17.4	8.16
7	15	119	14.7	7.95
13	20.5	81	20.4	7.29
20	19	118	19	5.61
43	19	160	18.2	4.40
50	20.5	250	23	4.06
63	26	231	25.2	3.57
90	26	210	25.2	2.83

\* Average between 1 and 1000 atm.

TABLE 10.—SPECIFIC GRAVITY (1)

% Al	$d_4^{20}$	% Al	$d_4^{20}$	% Al	$d_4^{20}$
0	8.92	15.0	6.93	64	3.68
7	7.83	22.5	6.08	82	3.09
12.5	7.30	35	4.88	100	2.69
14.7	6.97	46	4.26		

TABLE 11.—EFFECT OF COLD ROLLING AND ANNEALING ON MECHANICAL PROPERTIES OF CU, 92.99; AL, 7.03 (17)

Treatment (rolled plate)	UTS		$El^*$		BHN†
	L†	T†	L†	T†	
$R_h$ 16 mm, $R_e$ 8 mm.....	74.0	74.4	10	9	183
$R_h$ 20 mm, $R_e$ 8 mm.....	79.6	80.2	9	4	205
$R_h$ $R_e$ A 500°.....	50.5	50.6	46	111	111
$R_h$ $R_e$ A 600°.....	46.0	54.7	57	75	75

\* On 50 mm.

† L, T specimens taken parallel and perpendicular to direction of rolling, respectively.

‡ 10 mm ball, 500 kg load.



TABLE 11.—EFFECT OF COLD ROLLING AND ANNEALING ON MECHANICAL PROPERTIES OF CU, 92.99; AL, 7.03 (17).—(Continued)

Ann. temp., °C	UTS*	El*	Ann. temp., °C	UTS*	El*
(R <sub>h</sub> )	75.8	8	305	79.0	6
100	76.3	7	335	76.9	6
155	77.2	3	360	67.4	13
180	77.2	7	385	62.7	17
210	78.6	6	410	55.4	30
230	79.7	6	460	52.3	40
260	79.7	6	510	51.1	40
285	79.7	5			

\* R<sub>h</sub> 16 mm, R<sub>c</sub> 8 mm (||).

Ann. temp., °C	BHN†	Ann. temp., °C	BHN†
(R <sub>h</sub> )	205	290	222
70	204	315	218
120	206	340	192
170	209	365	152
195	210	390	138
215	209	415	123
240	216	465	114
265	217	515	111

† R<sub>h</sub> 20 mm, R<sub>c</sub> 8 mm (||).

TABLE 12.—EFFECT OF HEAT TREATMENT ON ROLLED CU, 90; AL, 10\* (19)

Treatment	UTS	YP	El†	BHN	ScH‡	IS§
R A 750°/90	49		14	125¶	19.2	3.5**
R W 500°	48		13	125¶	18	3.2**
R W 600°	61		20.5	121¶	27	7**
R W 700°	60		22	122¶	26.5	8**
R W 800°	72		9	148¶	46.7	6.1**
R 800°/10 Q <sub>w</sub>	69.2	23.3	8	184††	49	6.2††
400°	73.9	23.4	2.5	205††	55	3.8††
500°	62	29.5	12	162††	42.5	4.6††
600°	59.2	22.3	21.7	144††	38	8.6††
700°	51.2		13.5	120††	32	10.5††
R 900°/20 Q <sub>w</sub>	67.7	39.7	3.5	223††	44	4††
400°	64.1	45.5	2.2	208††	69.7	5.7††
500°	60.6	34.4	12.0	152††	46	8.6††
600°	60.7	27.7	26.5	133††	41.6	12.5††
700°	57.6	29	22.7	129††	40.1	14.4††

\* Cu, 89.84; Al, 9.95; Zn, 0.11; (Si, Fe), Tr.

† Test pieces 10 mm square cross-section.

‡ Hardened steel point.

§ Guillery machine.

¶ Heated in salt bath.

¶ 10 mm, 1000 kg.

\*\* Copenhagen test piece.

†† 10 mm, 2000 kg.

‡‡ Mesnager test piece.

TABLE 13.—EFFECT OF HEAT TREATMENT ON CAST CU, 90; AL, 10 (7, 26)

t, °C	Trt A* BHN	Trt B* BHN	t, °C	Trt A* BHN	Trt B* BHN
(G <sub>a</sub> )	118		705	133	115
370		230	760	163	110
425	121	178	815	205	108
480		157	870	240	
540	128	140	925	240	
595	112	133	980	200	
650	121	125			

\* Trt A = Wt° Q<sub>w</sub>; Trt B = W 870° Q<sub>w</sub> Tp t°; BHN: 10 mm, 1000 kg.

TABLE 13.—EFFECT OF HEAT TREATMENT ON CAST CU, 90; AL, 10 (7, 26).—(Continued)

Treatment	UTS	EL	EL
G <sub>a</sub>	42.2	10.5	28.5
800° Q <sub>w</sub>	68.9	21.8	8.0
900° Q <sub>w</sub>	66.8	38.7	3.5
Same, Tp { 500°	60.5	34.4	12.0
705°	56.2	28.8	22.7

Treatment	UTS	EL	EL <sub>a</sub>	RA	BHN
G <sub>a</sub>	52.0	13.9	19.5	23.7	100
900° Q <sub>w</sub>	74.0	28.5	1.0	0.8	262
Same, Trt	68-64	40-27.5	5.5-14	9-18.5	158-140

TABLE 14.—EFFECT OF HEAT TREATMENT ON HARDNESS OF CAST CU, 90; AL, 10\* (6)

Tempering temp., °C	ScH		BHN† (heat A), at:			BHN† (heat H), at:		
	Heat A	Heat H	3000 kg	1000 kg	500 kg	3000 kg	1000 kg	500 kg
None	43-54	46-55	248	249	206	248	244	
150	48-55	56-58	241	249		235	238	
205	50-55	52-56	241	238		241	249	
260	53-57	53-58	262	260		255	249	
315	46-53	57-61	262	260		269	260	
400	49-60	56-62	262	260		269	260	
480	30-32	34-36	170	165		179	171	
565	23-27	23-26	163	159	136		159	143
650	21-22	22-24		133	124		138	130
760	19-20	19-20		121	100		121	109
870	18-19	20-21	131	113	100	134	117	109

\* Disks ¼ in. thick cut from tensile test stubs of cast alloy having: UTS = 45-53; YP = 15-18; EL = 17-23 %; RA = 16-26 %. Stubs W 900°/20-30 Q<sub>w</sub> Tp t° C<sub>CaO</sub>.  
† 10 mm ball.

Tempering temp., °C*	ScH†		BHN (3000 kg)	
	Heat A	Heat F	Heat A‡	Heat F‡
None	55-59	58-61	255	269
150	54-57	55-59	248	277
205	54-57	56-61	241	269
260	55-58	59-61	269	277
315	52-55	57-61	262	286
345	54-57	58-62	262	286
370	48-52	55-58	277	286
400	48-50	50-53	269	269
425	36-39	42-44	196	255
455	25-27	38-42	183	223
480	21-24	29-31	179	202
510	20-22	26-28	170	196

Tempering temp., °C	Air cooled§		Cooled in CaO§	
	ScH	BHN	ScH	BHN
None	60-65		59-66	
150	62-66	249		
205			61-63	260
230	62-67	260		
260			60-63	244
315	62-66	285	65-70	278
345	63-70	279	60-64	272
370	60-66	255		
400	59-62	255		
425	48-55	205		

\* Same treatment as above except where air cooled.

† On flattened surface of edge of disks ¼ in. thick.

‡ On faces of same disks.

§ On flats filed on tensile test stubs.

|| Load = 1000 kg.

TABLE 15.—EFFECT OF HEAT TREATMENT ON HARDNESS AND  
ENDURANCE TO REVERSED BENDING OF CAST Cu, 90; Al, 10  
(22)

Cu, 90.5; Al, 9.5									
Quench temp., °C* . . . .	900	800	700	600	500	400	300	200	Room
No. bends† . . . . .		230	400	1340	1200	850	500	600	200
BHN (10 mm, 500 kg) . .	86	89	80	74	67	65	66	63	70

\* 900° C<sub>8</sub> W t° Q<sub>w</sub>. † Arnold machine.

Cu, 90; Al, 10

Treatment		No. bends	BHN
G . . . . .		650	
G, A {	300° . . . . .	600	
	400° . . . . .	550	
	500° . . . . .	130	
	650° . . . . .	630	
	800° . . . . .	1050	
900° Q <sub>w</sub> . . . . .		5	130
Same, A {	400° . . . . .	7	123
	500° . . . . .	50	119
	600° . . . . .	300	100
900° Q <sub>w</sub> A {	700° . . . . .	500	93
	800° . . . . .	470	80
800° Q <sub>w</sub> . . . . .		2	
Same, A {	400° . . . . .	2	143
	500° . . . . .	10	100
	600° . . . . .	270	80
	700° . . . . .	355	86
700° Q <sub>w</sub> . . . . .		6	100
Same, A {	400° . . . . .	150	93
	500° . . . . .		86
	600° . . . . .	400	74
600° Q <sub>w</sub> . . . . .		400	86
Same, A {	400° . . . . .	300	80
	500° . . . . .	84	86
500° Q <sub>w</sub> . . . . .		40	84
Same, A 400° . . . . .		20	86

Cu-Al-Fe

TABLE 16.—AVERAGE PROPERTIES (13)

% Al	% Fe	Treatment	UTS	YP	EL	RA	DL <sub>C</sub>	BHN
10	1	G <sub>s</sub> . . . . .	46-53	14-21	24	27	13-14	92-96
10	3	Wk <sub>d</sub> rod . . . . .	91		5			
		Wk <sub>s</sub> rod . . . . .	63		30			
9	3	G <sub>s</sub> . . . . .	46-56	25-32	20-40	20-40	10-13	95-120
8	3	Wk <sub>d</sub> rod . . . . .	88		5			
		Wk <sub>s</sub> rod . . . . .	51		50			

U. S. master specification (No. 173) for Al-bronze ingots: Cu, 85-89; Al, 7.0-9.0; Fe, 2.5-4.5; Sn, <0.5; other elements, <0.25. UTS < 52.7 kg/mm<sup>2</sup>; YP < 21.1 kg/mm<sup>2</sup>; EL<sub>a</sub> < 30%.

Proposed U. S. master specification for Al-bronze eastings: Desired: Cu, 88; Al, 9.0; Fe, 3.0; Sn, 0; other elements, 0. Permissible: Composition, UTS, and EL<sub>a</sub> as for ingots.

TABLE 17.—TENSILE PROPERTIES AND HARDNESS OF SAND CAST  
ALLOYS\* (10)

% Al	% Fe	UTS	YP†	PL	EL <sub>a</sub>	RA	BHN‡
7	1	37.4	11.0	10.1	56.0	54.2	70
	2	44.3	13.3	12.2	39.0	35.6	70
	3	52.4	16.4	15.0	38.0	32.2	80
	4	53.7	16.6	15.5	38.5	35.7	89
	5	51.7	17.4	15.2	29.0	26.9	
	6	54.5	17.8	15.1	31.5	27.6	
8	8	52.4	18.0	16.6	27.5	27.6	
	1	40.1	13.7	11.5	45.0	43.4	70
	2	44.8	14.5	12.8	39.0	39.2	80
	3	57.0	18.3	17.0	36.5	32.9	109
9	4	57.7	18.5	17.4	35.0	32.0	109
	1	48.8	16.4	13.0	43.0	35.7	77
	2	55.0	18.1	15.7	30.5	27.4	109
	3	57.4	19.9	18.0	26.0	26.9	109
10	4	58.3	20.0	18.6	23.0	23.8	109
	1	54.1	16.9	13.9	24.5	25.2	94
	2	58.1	18.8	16.0	21.0	19.2	100
	3	60.7	20.2	18.3	20.0	20.5	109
	4	62.3	21.1	19.3	17.0	18.5	119
	5	56.6	23.2	20.7	12.5	16.9	
	6	60.1	23.5	21.8	13.0	14.7	
	8	60.8	25.2	22.4	11.5	12.4	

\* All specimens ½ in. diam., sand cast.

† By dividers.

‡ 10 mm ball, 500 kg load applied 30 sec.

TABLE 18.—PROPERTIES OF LARGE AND SMALL CASTINGS (8)

*v. also Table 21*

Treatment and description	UTS	YP	EL	RA
Cu, 89.0-89.5; Al, 9.5-10.0; Fe, 1.0				
G (semi-chill) 1.25 in. diam.	53.4-55.5	13.4-14.1*	28-30	27-31
Large gear . . . . .	45.1	18.1	12.0	14.7
Small bars cast with large	37.9-49.2	17.6-21.1	10-20	12-23
Machined from same large				
casting . . . . .	36.5-40.1	16.2-18.3	12-14	14-20
G ½ in. sq. unmachined . . .	53.1	14.5	24	22.4
G ½ in. diam. unmachined				
(av.) . . . . .	54.1	16.9	24.5	25.2
Cu, 88; Al, 9; Fe 3				
	49.2	21.1	20	

\* PL.

TABLE 19.—TENSILE PROPERTIES AND YOUNG'S MODULUS (5)

Treatment and test method*	UTS	YP	PL	EL	EL <sub>a</sub>	RA	10 <sup>-2</sup> E
Cu, 89; Al, 10; Fe, 1							
G <sub>s</sub> , method A . . . . .	51.2	18.8	8.9	7.9	22.0	22.7	
G <sub>s</sub> , method B . . . . .	51.1		9.1		29.0	26.1	102
G <sub>s</sub> , method C . . . . .	51.6	18.7	7.7	6.0	20.5	21.6	109
G <sub>s</sub> , Trt, method A . . . . .	65.2	40.3	21.8	18.3	12.6	14.8	
G <sub>s</sub> , Trt, method C . . . . .	57.5	36.3	23.9	21.1	9.0	16.5	105
Cu, 86; Al, 10; Fe, 4							
G <sub>s</sub> , method A . . . . .	56.7	22.6	12.4	11.2	18.0	18.6	
G <sub>s</sub> , method B . . . . .	49.9		14.4		9.0	10.4	112
G <sub>s</sub> , Trt, method A . . . . .	70.3	41.8	25.4	20.5	16.0	17.2	

\* Method A: Berry strain gage used for E, EL, PL and YP, in one position only. Method B: Mean of three strain gage readings taken, gages 120° apart. Method C: Special extensometer giving mean of strains on opposite sides used.



TABLE 20.—BRINELL HARDNESS NUMBER\* AT HIGH TEMPERATURES (12)

No.	$t, ^\circ\text{C}$	20	250	350	450	550	600	650	700	800	900	950
1†		125	84.5	82.5	80	69.8	51		34.5	20	11.5	10.5
2†		131.5	125.2	117.5	96.6	79.6		14.5	9.8			

\* 10 mm, 500 kg.

† No. 1: Al, 7.64; Fe, 2.12; Mn, 0.49. No. 2: Al, 10.55; Fe, 4.22; Mn, 0.74.

TABLE 21.—EFFECT OF HEAT TREATMENT ON SAND CAST ALLOYS\* (4, 9)

Treatment	Size†	UTS	PL	El	RA	BHN‡	
G <sub>s</sub> .....	A	52.0	13.9	19.5	23.7	100	
600° Q <sub>w</sub> .....	A	55.9	10.8	21.0	22.2		
850° Q <sub>w</sub> §.....	A	68.4	28.0	1.0	0.0	240	
850° C <sub>a</sub> 10s Q <sub>w</sub> .....	A	73.9	28.5	1.0	0.8	262	
850° C <sub>a</sub> 20s Q <sub>w</sub> .....	A	64.3	23.3	2.0	5.7	229	
850° C <sub>a</sub> 30s Q <sub>w</sub> .....	A	51.4	16.6	5.0	9.4	150	
850° C <sub>a</sub> 45s Q <sub>w</sub> .....	A	50.9	11.0	7.0	12.2		
850° Q <sub>w</sub> , W 650°/15 { C <sub>a</sub> ..	A	60.9	24.7	13.0	14.9	130	
	C <sub>f</sub> ..	66.0	30.2	12.5	12.3	143	
850° Q <sub>w</sub> , W {	500°/30 C <sub>f</sub> .....	A	67.5	39.8	5.5	9.1	158
	575°/20 C <sub>f</sub> .....	A	66.1	32.4	8.0	11.2	143
	610°/15 C <sub>f</sub> .....	A	68.0	30.4	10.5	12.6	140
	650°/15 C <sub>f</sub> .....	A	64.1	27.6	14.0	18.5	143
	700°/15 C <sub>f</sub> to 550°, C <sub>a</sub>	A	56.2	16.4	23.0	21.7	104
G <sub>s</sub> .....	B	40.3	12.7	12.5	15.0		
850° Q <sub>w</sub> , W {	600° C <sub>f</sub> .....	D	65.6	37.7	10.0	13.5	
	630° C <sub>f</sub> .....	D	62.2	30.4	13.0	14.2	
	650° C <sub>f</sub> .....	C	52.0	24.3	14.5	17.6	
	650° C <sub>f</sub> .....	B	59.8	28.7	12.5	15.7	
	650° C <sub>f</sub> .....	B	55.0	27.9	9.5	15.0	
	650° C <sub>f</sub> .....	B	52.5	28.3¶	9.0	13.5	
G <sub>s</sub> A.....	B	38.8	16.0	9.0	11.2	109	

\* Cu, 88.63; Al, 10.67; Fe, 0.91.

† A = cast to size 0.493–0.521 in. diam., 2 in. gage length. B = Trt in 2 × 4 × 9 in. block size. C = Trt in 2¼ in. diam. size. D = Trt in 1½ in. diam. size.

‡ 10 mm, 500 kg except those marked ||.

|| 10 mm, 3000 kg.

§ Adopted as proper quenching temperature.

¶ This value is a YP.

## Cu-Al-Mn

TABLE 22.—TENSILE PROPERTIES\* (25)

v. also Table 26

Treatment†	10 × UTS	10 × YP‡	El <sub>a</sub>	RA
Cu, 89.54; Al, 10.03; Mn, 0.43				
G <sub>s</sub> .....	517	225	24	
G <sub>m</sub> .....	567	251	24	
R <sub>h</sub> 1¼ in. diam.....	635	294	24.5	
R <sub>h</sub> 1⅜ in. diam.....	621	309	31	29.2
D <sub>c</sub> 1⅜ in. diam.....	728	662	13	18.8
Cu, 89.10; Al, 9.89; Mn, 1.01 and (Cu, 89.06; Al, 10.02; Mn, 0.92)§				
G <sub>s</sub>   .....	563	221	22.5	
A 550°/1 h.....	446	200	15.0	
A 800°/1 h.....	459	208	17.0	
550°/1 h Q <sub>w</sub> .....	501	214	18.5	
800°/1 h Q <sub>w</sub> .....	650	205	6.0	
800°/15 Q <sub>w</sub> .....	599	208	7	
G <sub>m</sub>   .....	629	252	25.0	
R <sub>h</sub> 1¼ in. diam.  .....	600	270	26.5	32.4
R <sub>h</sub> 1⅜ in. diam.....	658	291	30	

TABLE 22.—TENSILE PROPERTIES\* (25).—(Continued)

Treatment†	10 × UTS	10 × YP‡	El <sub>a</sub>	RA
R <sub>h</sub> 1⅜ in. diam.  .....	675	363	22.5	33.6
A 550°/1 h.....	589	340	5.0	
A 800°/1 h.....	545	241	31.0	
A 900°/6 h.....	501	203	29	
550°/1 h Q <sub>w</sub> .....	621	321	16.0	
880°/1 h Q <sub>w</sub> .....	717	381	11.5	
D <sub>c</sub> 1⅜ in. diam.  .....	788	662	16.0	
Cu, 88.00; Al, 9.99; Mn, 2.01 and (Cu, 88.30; Al, 9.82; Mn, 1.88)§				
G <sub>s</sub> .....	542	208	24	
A 550°/1 h.....	507	173	15	
A 850°/1 h.....	630	205	12	
550°/1 h Q <sub>w</sub> .....	534	195	11	
850°/1 h Q <sub>w</sub> .....	647	284	5	
850°/15 Q <sub>w</sub> .....	646	208	7	
G <sub>m</sub> .....	583	265	25	
R <sub>h</sub> 1¼ in. diam.....	637	287	35.0	31.3
R <sub>h</sub> 1⅜ in. diam.  .....	659	284	24	
R <sub>h</sub> 1⅜ in. diam.....	642	337	29.0	32.0
A 550°/1 h.....	614	350	7.5	
A 850°/1 h.....	559	230	26.5	
A 900°/6 h.....	536	195	24	
550°/1 h Q <sub>w</sub> .....	662	301	25.0	
850°/1 h Q <sub>w</sub> .....	819	397	3.5	
D <sub>c</sub> 1⅜ in. diam.....	820	644	10.0	
Cu, 89.91; Al, 9.16; Mn, 0.93				
G <sub>s</sub> .....	484	176	46.5¶	
G <sub>m</sub> .....	534	205	46.0	
R <sub>h</sub> 1¼ in. diam.....	572	257	45.0	46.0
R <sub>h</sub> 1⅜ in. diam.....	603	335	41.5	54.0
Cu, 88.99; Al, 9.06; Mn, 1.95				
G <sub>s</sub> .....	494	167	40.0¶	
G <sub>m</sub> .....	523	223	30.0	
R <sub>h</sub> 1¼ in. diam.....	585	265	43.5	47.2
R <sub>h</sub> 1⅜ in. diam.....	613	321	42.0	48.0
D <sub>c</sub> 1⅜ in. diam.....	667	581	23.5	40.8
Cu, 88.06; Al, 9.10; Mn, 2.84 and (Cu, 88.11; Al, 8.91; Mn, 2.98)§				
G <sub>s</sub>   .....	498	170	24**	
A 550°/1 h.....	492	204	35	
A 900°/1 h.....	426	164	49	
550°/1 h Q <sub>w</sub> .....	501	227	31.5	
900°/1 h Q <sub>w</sub> .....	620	271	9	
900°/15 Q <sub>w</sub> .....	567	249	11.5	
G <sub>m</sub>   .....	542	233	26	
R <sub>h</sub> 1¼ in. diam.  .....	609	284	43.5	46.0
R <sub>h</sub> 1⅜ in. diam.  .....	630	315	39.0	43.6
R <sub>h</sub> .....	649	303	40.0	
A 550°/1 h.....	646	350	27.0	
A 900°/1 h.....	501	199	43.0	
A 900°/6 h.....	487	196	37.5	
550°/1 h Q <sub>w</sub> .....	492	320	39.0	
900°/1 h Q <sub>w</sub> .....	689	314	23.0	
D <sub>c</sub> 1⅜ in. diam.....	693	613	22.0	40.0
Cu, 86.89; Al, 9.33; Mn, 3.78				
G <sub>s</sub> .....	506	193	20.0	
G <sub>m</sub> .....	624	238	32.0	
R <sub>h</sub> 1¼ in. diam.....	601	265	34.0	38.4
R <sub>h</sub> 1⅜ in. diam.....	639	286	35.0	38.0
D <sub>c</sub> 1⅜ in. diam.....	689	641	21.0	34.0

TABLE 22.—TENSILE PROPERTIES\* (25).—(Continued)

Treatment†	$10 \times UTS$	$10 \times YP$ ‡	$El_a$	RA
Cu, 88.04; Al, 8.02; Mn, 3.94				
G <sub>s</sub> .....	454	180¶	31.5	
G <sub>m</sub> .....	521	208	50.0	
R <sub>h</sub> 1¼ in. diam.....	561	257	49.0	56.0
R <sub>h</sub> 1⅜ in. diam.....	590	295	45.0	54.0
D <sub>c</sub> 1⅜ in. diam.....	624	549	35.0	55.2
Cu, 87.16; Al, 7.92; Mn, 4.92				
G <sub>s</sub> .....	441	177	30.0	
G <sub>m</sub> .....	479	195	28.0	
R <sub>h</sub> 1¼ in. diam.....	571	277	52.0	54.8
R <sub>h</sub> 1⅜ in. diam.....	577	304	45.0	51.2
D <sub>c</sub> 1⅜ in. diam.....	649	548	30.0	49.2

\* Alloys contained small amounts of Fe and Si which should be deducted from figures for Al; amounts are given for only three alloys in original paper.

† For more detailed statement of treatments v. footnote to Table 2. There was no material difference between G<sub>s</sub> to shape and G<sub>s</sub> machined.

‡ By dividers.

§ Tests on alloy in parentheses, are indicated by || in column 1 of this section.

¶ Discrepancy between two tests of ca. 13 %.

\*\* Broke outside gage marks.

TABLE 23.—TENSILE PROPERTIES AT HIGH TEMPERATURES (25)

$t, ^\circ C^*$	Al, 9.89; Mn, 1.01		
	UTS	YP	$El_a$
200	62.4	24.1	36.5
250	62.2	29.6	43.0
300	57.3	30.7	47.0
350	51.9	30.6	40.0
400	35.8	21.8	57.0
450	27.2	18.4	51.0
Al, 9.99; Mn, 2.01			
200	62.3	30.3	28.0
250	61.6	31.6	35.0
300	58.3	26.3	45.0
350	49.3	26.8	45.0
400	31.8	22.1	41.5
450	22.0	15.6	35.5
Al, 9.10; Mn, 2.84			
200	62.4	29.8	40.5
250	62.0	32.8	47.0
300	56.1	31.0	37.0
350	46.8	29.3	36.0
400	32.2	21.3	39.5
450	20.4	14.4	56.0
500	14.5		38.0

\* Held at this temperature 30 min before testing.

TABLE 24.—HARDNESS AND TORSIONAL STRENGTH OF HOT ROLLED ALLOYS\* (5)

% Al	% Mn	BHN† (A)	BHN† (B)	ScH	UTS	USSC	TMR	Twist, °/cm
10.03	0.43	170	199	27	63.5	35.7	47.6	26.3
10.02	0.92	158	190	27	60.0	34.6	46.2	26.6
9.82	1.88	164	193	27	63.7	37.6	50.2	35.8
9.16	0.93	146	171	23	57.2	34.6	46.2	40.3
9.06	1.95	165	184	24	58.5	37.5	50.1	46.3
8.91	2.98	158	187	25	60.9	37.5	50.1	43.9
9.33	3.78	165	186	25	60.1	35.7	47.6	33.4
8.02	3.94	159	170	22	56.1	37.5	50.1	66.6
7.92	4.92	149	169	22	57.1	38.5	51.4	72.4

\* From 1¼ in. diam. bars, torsion pieces 3 × 0.624 in. diam.

† A = 1034 kg, B = 3000 kg, ball diam. = 9.52 mm.

TABLE 25.—DYNAMIC STRESS TESTS ON HOT ROLLED ALLOYS\* (25)

Reversed bend test					
% Al	% Mn	No. bends†			
10.03	0.43	877			
10.02	0.92	1104			
9.82	1.88	933			
9.16	0.93	741			
9.06	1.95	738			
8.91	2.98	680			
9.33	3.78	694			
8.02	3.94	441			
7.92	4.92	423			
Single blow impact			Impact bending test		
% Al	% Mn	IS‡ (Izod)	Wt. of Tup, kg	Ht. of Fall, cm	No. blows§
10.02	0.92	1.37	2.79	5.11	918
			2.14	2.57	10 006
9.82	1.88	1.37	2.79	5.11	762
			2.14	2.57	12 713
8.91	2.98	1.44	2.79	5.11	600
			2.14	2.57	11 396

\* Test pieces taken from hot rolled bars 1⅜ in. diam. For fatigue endurance limits v. p. 595.

† Test piece ⅜ in. diam., Arnold machine.

‡ Notched specimen 2 × ⅜ × ⅜ in.

§ Test piece ½ in. diam., V notch, bottom diam. = 0.4 in., Bairstow machine.

TABLE 26.—ELASTIC PROPERTIES\* (25)

% Al	% Mn	$10^{-3} E$	PL
R <sub>h</sub> , to 1⅜ in. diam.			
10.02	0.92	9.56	12.8
9.82	1.88	9.77	14.5
8.91	2.98	10.47	19.2
D <sub>c</sub> , to 1⅜ in. diam.			
9.89	1.01	9.49	19.4
9.99	2.01	9.28	19.4
8.91	2.98	10.40	24.1

\* By Ewing extensometer.

TABLE 27.—SPECIFIC GRAVITY ( $d_4^{20}$ ) (25)

% Al	% Mn	Trt	G <sub>s</sub>	G <sub>m</sub>	R <sub>h</sub>	D <sub>c</sub>
10.03	0.43		7.62	7.55	7.54	
10.02	0.92		7.53	7.51	7.52	7.56
9.82	1.88		7.62	7.51	7.53	7.52
9.16	0.93		7.64	7.55	7.61	
9.06	1.85		7.57	7.63	7.60	
8.91	2.98		7.57	7.57	7.59	7.59
9.33	3.78		7.52	7.63	7.56	
8.02	3.94		7.64	7.73	7.67	
7.92	4.92		7.65	7.76	7.63	7.60

TABLE 28.—EFFECT OF ANNEALING ON PROPERTIES OF COLD ROLLED SHEET (24)

% Al	% Mn	Trt*	UTS	YP	El†	BHN‡
2	5	R.....	47.1	46.6	9	145
		A.....	35.3	16.4	45	83
3	0	R.....	42.2	41.9	9	137.5
		A.....	27.9	9.1	55	60
3	1	R.....	42.2	41.3	11.5	141.5
		A.....	31.8	15.8	50	72.5
3	3	R.....	43.6	43.0	12	140
		A.....	33.7	16.1	48	78.5



TABLE 28.—EFFECT OF ANNEALING ON PROPERTIES OF COLD ROLLED SHEET (24).—(Continued)

% Al	% Mn	Trt*	UTS	YP	El†	BHN‡
4	5	R.....	56.2	55.1	15.5	182
		A.....	42.1	17.8	55	95
5	0	R.....	55.3	54.0	16.5	174.5
		A.....	40.2	13.1	70	84.5
5	1	R.....	49.0	45.2	27	162.5
		A.....	41.4	18.9	57	89.5
6	3	R.....	61.4	60.2	12	
		A.....	46.9	21.6	58	
7	0	R.....	62.7	61.0	17.5	195
		A.....	43.3	11.0	71	75.5
7	1	R.....	55.9	53.7	28	184
		A.....	46.1	18.1	65	99.5

\* R =  $G_{phm} R_h$  (1.5–3% in.)  $P_{wRc}$  0.14 in. A = A 650°/30  $C_a$ .

† On 2½% in.

‡ 5 mm, 300 kg.

TABLE 29.—EFFECT OF ANNEALING ON SCLEROSCOPE HARDNESS OF COLD DRAWN BARS\* (22)

% Al	Ann. $t$ , °C		20	250	400	550	700	900
	% Mn							
10.02	0.92		34.5	34.5	34.5	25	20	16
9.82	1.88		34	33.5	33	25	19	18
8.91	2.98		29	29	29	21.5	16	15

\* Specimens exposed 30 min to each temperature in succession.

TABLE 30.—EFFECT OF HEAT TREATMENT ON PROPERTIES OF ROLLED Cu, 88.8C; AL, 10.02; MN, 1.1; ZN, 0.05; (SI, FE), Tr. (19)

Treatment	UTS	YP	El <sup>*</sup>	BHN	ScH <sup>†</sup>	IS <sup>‡</sup>		
R A . . . . .	48.5		13	120§	37.2	3.6¶		
R W 500°	5 m Q <sub>w</sub> . . . . .	{	47.1	11	122§	38	2.5¶	
R W 600°			57	13	128§	35	6.8¶	
R W 700°			59	16	123§	28	8¶	
R W 800°			64.2	2.2	187§	53	5¶	
R 800°/10 Q <sub>w</sub> . . . . .	68.7	23.9	2.2	222	58.2	5**		
Same, W 10 m	{	400° . . . . .	80.1	23.3	1	231	69.5	3.8**
		500° . . . . .	61.1	24	12	162	41.7	6.2**
		600° . . . . .	61.4	22.5	31.7	138	35.0	15.6**
		700° . . . . .	48.4	21.5	32	124	35.2	16.8**
R 900°/20 Q <sub>w</sub> . . . . .	66.1		0	203	40.2	9.7**		
Same, W 10 m	{	400° . . . . .	65.8	42	1	228	84.6	4**
		500° . . . . .	59.1	32.3	12	167	49.5	9.7**
		600° . . . . .	62.6	29	21.2	140	45	14.9**
		700° . . . . .	60	27	25.1	128	39.4	17.7**

\* Test pieces 10 mm square.

† Hardened steel point.

‡ Guillery machine.

§ 10 mm, 1000 kg.

|| 10 mm, 2000 kg.

¶ Copenhagen test piece.

\*\* Mesnager test piece.

## Cu-Al-Ni

TABLE 31.—PROPERTIES OF ALLOYS CONTAINING UP TO 10% AL, 15% NI (21)

Treatment	UTS	YP	PL	El*	RA	BHN	ScH	$d_4^{20}$	No. bends†
Cu, 94.98; Al, 5.02 and (Cu, 94.88; Al, 5.12)‡									
$G_m$ .....	29.5§	7.9§		68.0§	58.2§	58	9.0		
R A 900°  .....	34.9	8.2		82.5	78.9	61	8.5	8.18	741
R, W 900° $Q_w$ ¶.....	35.9	10.1**		78.6	73.3	52††	11.0	8.18	1045
$R_c$ .....	42.8	27.4		64.0	75.1	114	17.0	8.17	773

TABLE 31.—PROPERTIES OF ALLOYS CONTAINING UP TO 10% AL, 15% NI (21).—(Continued)

Treatment	UTS	YP	PL	El <sub>a</sub> *	RA	BHN	ScH	d <sub>4</sub> <sup>20</sup>	No. bends†
Cu, 93.96; Al, 5.10; Ni, 0.94 and (Cu, 93.94; Al, 5.06; Ni, 1.00)‡									
G <sub>m</sub> .....	30.3§	8.7§		92.1§	69.1§	59	10.5		
R A 900°  .....	35.9	8.3		94.6	76.1	64	10.5		746
R, W 900° Q <sub>w</sub> ¶.....	36.0	10.4**		85.6	73.8	56††	11.0		862
R <sub>c</sub> .....	44.4	28.5		63.1	78.1	113	18.5		580
Cu, 92.68; Al, 4.94; Ni, 2.38									
G <sub>m</sub> .....						59	11.0	8.14	
R A 900°  .....	36.0	8.7		90.2	71.0	66	11.0	8.17	671
R, W 900° Q <sub>w</sub> ¶.....	39.1	11.3		77.8	71.4	62††	11.5	8.16	738
R <sub>c</sub> .....	47.4	35.4		55.0	66.7	124	210	8.16	354
Cu, 89.84; Al, 5.32; Ni, 4.84 and (Cu, 90.04; Al, 4.91; Ni, 5.05)‡									
G <sub>m</sub> .....	29.4§	8.8§		86.5§	73.4§	60	12.0	8.15	
R A 900°  .....	40.3	14.8		70.0	60.2	80	12.5	8.18	445
R, W 900° C <sub>a</sub> .....	37.5	12.0		81.0	68.7				
R A 900°.....	44.2	16.5	9.5	56	52				
R, W 900° Q <sub>w</sub> ¶.....	38.1	11.9		86.8	72.4				
	38.0	12.0**	6.3	85	71	61††	12.0	8.18	400
R <sub>c</sub> .....	49.0	37.0		50.0	72.3	136	23.0	8.17	229
Cu, 87.48; Al, 5.21; Ni, 7.31 and (Cu, 87.30; Al, 5.39; Ni, 7.31)‡									
G <sub>m</sub> .....	32.2§	11.7§		79§	59§	77	13.5	8.15	
G <sub>m</sub> A 900°††.....	52.5§	35.9§		10.5§	19§	171§			
R A 900°  .....	61.4	37.8		25.6	26.8	167	27.0	8.19	193
R, W 900° C <sub>a</sub> .....	42.6	18.3		63.9	69.9				
R A 900°††.....	64.5	39.4	25.2	17	21				
R, W 900° Q <sub>w</sub> .....	46.9	17.9**		52.1	65.1				
	43.2	12.9	6.3	63	69	92††	17.0	8.18	258
R <sub>c</sub> .....	57.2	49.0		28.8	41.0	156	27.5	8.18	150
Cu, 87.32; Al, 5.34; Ni, 7.34									
R <sub>c</sub> ½ in. diam.....	84.1	81.1	9.5	12	38				
A 100°/30 m.....	79.1	77.7	14.2	12	43				
A 200°/30 m.....	76.4	74.8	23.6	13	41				
A 300° { 30 m.....	75.0	72.9	42.5	12	48				
68 h.....	73.1	69.0	45.7	24	58				
A 420°/30 m.....	70.6	67.4	50.4	20	47				
A 500° { 15 m.....	76.9	72.9	58.3	21	45				
	30 m.....	77.3	73.2	52.0	41				
	1 h.....	80.2	76.4	55.1	49				
	4 h.....	79.7	69.6	47.3	36				
6 h.....	78.6	67.7	36.2	21	35				
A { 600°	30 m... {	68.8	55.6	37.8	23	38			
		61.9	46.5	31.5	34	51			
		52.5	26.5	23.6	50	64			
R ½ in. diam. { Q <sub>w</sub> ...	C <sub>a</sub> ††.....	41.0	12.6	6.3	72	69			
		65.1	39.4	26.8	22	23			
R ½ in. diam. { Q <sub>w</sub> ...	C <sub>a</sub> §§.....	45.2	13.9	6.3	68	70			
		60.3	30.7	18.9	28	32			
900° Q <sub>w</sub> (½ in. diam.)		45.2	13.9	6.3	68	70			
Same, Tp {	C <sub>a</sub> {	600°/30	61.2	36.5	25.2	17	25		
		600°/2 h	64.2	40.9	28.4	13	20		
		700°/30 h	65.3	35.4	23.6	28	32		
		800°/30	51.6	20.3	13.4	44	43		
		815°/30	46.8	15.1	9.5	67	67		
R <sub>c</sub> ½ in. diam.....	61.5	57.9	28.3	20	43	177			
R <sub>h</sub> ½ in. diam.....	69.3	63.5	47.3	20	52	235			
R <sub>c</sub> ½ in. diam.....	84.1	81.1	9.5	12	38	234			
Cu, 85.03; Al, 5.55; Ni, 9.42									
G <sub>m</sub> .....	44.5	23.6		39.7	39.0	115	17.0	8.13	
Cu, 79.90; Al, 5.20; Ni, 14.90									
G <sub>m</sub> .....	65.4	55.3		4.7	10.0	173	37.0	8.14	
Cu, 87.16; Al, 6.62; Ni, 6.22									
G <sub>m</sub> .....	32.0	10.1		77	70	69			
G <sub>m</sub> A 900° C <sub>a</sub> ††.....	50.6	25.2		19.5	25	147			
G <sub>m</sub> , W 900° Q <sub>w</sub> Tp  .....	48.2	29.8		8.5	17				
Cu, 87.45; Al, 6.93; Ni, 5.62									
R <sub>c</sub> ½ in. diam.....	89.0	87.2	18.9	9	32				
A { 100°	30..... {	85.2	82.8	22.1	12	38			
		84.3	83.1	31.5	9	38			
		83.3	82.2	53.6	12	43			
A 300°/68 h.....	82.7	80.0	56.7	14	47				





TABLE 32.—BRINELL HARDNESS NUMBER\* AT HIGH TEMPERATURES (12)

% Al	% Ni†	t, °C	20	250	350	450	550	600	700	800	900	950
7.22	4.01		89	83.8	81.9	79	76.5	65	39	21.5	12.5	9

\* 10 mm, 500 kg.

† Trace of Fe present.

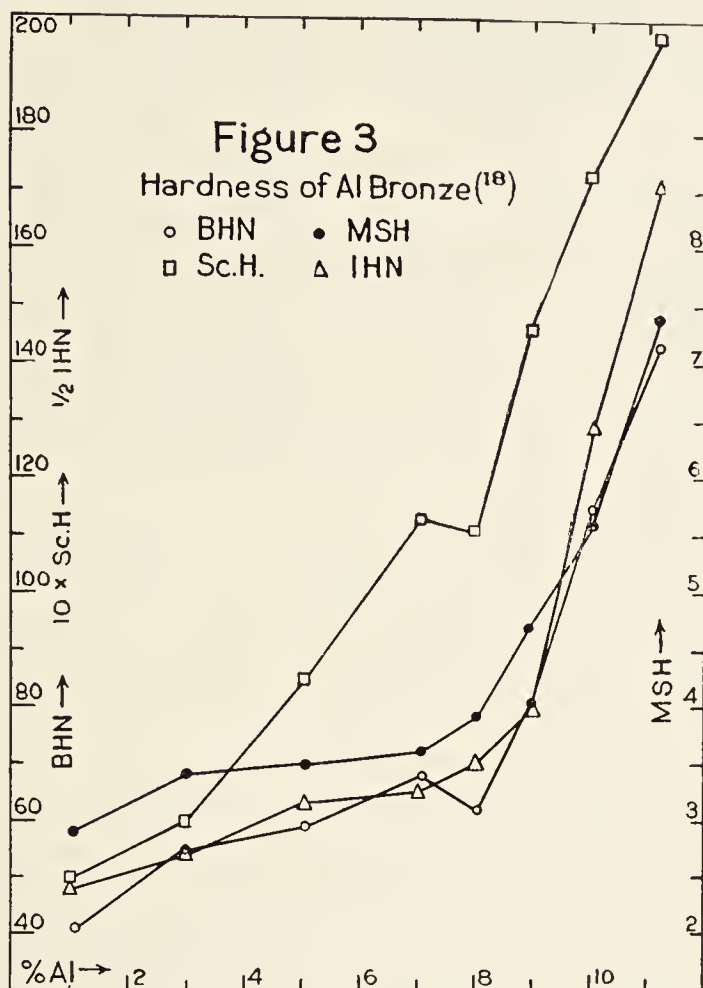


TABLE 33.—BRINELL HARDNESS NUMBER OF SPECIMENS COOLED AT DIFFERENT RATES (21)

% Al	% Ni	$\tau$	Q <sub>w</sub>	2	10	35	50	95	145	200
5.32	4.84	73	71	77	97	116	117	129	120	
5.21	7.31	87	84	154	176	168	148	159	145	
5.34	7.34	88	83	156	180	167	156	152	148	
6.93	5.62	91	90	148	152	152	140	139	137	
7.91	4.64	91	87	129	129	131	137	146	125	

 $\tau$  = Time in minutes taken to cool from 900 to 700°.Cu-Al-P  
TABLE 34.—Cu-AL-P ALLOYS (20)

Wt. % Al	P	M. P., °C	Trt*	UTS	YPT†	El <sub>a</sub>	RA	BHN†	ScH	No. bends
5.12			C <sub>m</sub> .....	29.5	7.9	68.0	58.2		8.5	
5.02		1054	{ A.....	38.5	9.5	79.1	79.0	77	9.0	741
			{ D <sub>c</sub> .....	42.9	27.4	64.0	75.1	114	17.0	773
4.97	0.06		{ G <sub>m</sub> .....						9.0	
			{ A.....	39.1	10.1	75.9	77.1	75	9.0	736
			{ D <sub>c</sub> .....	49.3	37.8	45.4	70.4	149	27.0	668
5.20	0.25	1045								
4.96	0.25		G <sub>m</sub> .....	28.5	8.5	35.2	31.5	74	9.0	
5.14	0.52	1042	G <sub>m</sub> .....	33.8	9.9	35.2	37.8	79	10.0	
5.30	0.75		G <sub>m</sub> .....	31.5	10.7	19.6	20.8	89	12.5	
5.28	1.02	1030	G <sub>m</sub> .....	24.7	14.5	9.7	13.0	94	13.7	
10.06		1038	{ G <sub>m</sub> .....						20.0	
			{ A.....	48.5	24.6	5.1	7.0	127	21.5	38
			{ D <sub>c</sub> .....	69.6	66.1	9.0	12.4	186	33.0	231
10.07	0.03		{ G <sub>m</sub> .....						19.5	
			{ A.....	51.4	26.0	6.8	5.5	158	23.0	36
			{ D <sub>c</sub> .....	71.8	69.9	6.7	8.4	196	35.0	327
10.27	0.18	1025	G <sub>m</sub> .....	42.8	8.8	8.3	13.4	156	24.5	
9.95	0.40§		G <sub>m</sub> .....	40.8	12.6	11.1	17.0	130	20.0	
9.70	0.50§	1019	G <sub>m</sub> .....	29.5	9.1	3.9	9.2	133	22.5	

\* A = A 800°/10 C<sub>gm</sub>.

† By autographic recorder.

‡ 10 mm, 300 kg.

§ Distinct smell of PH<sub>3</sub> on turning down.

## Cu-Al-Si

TABLE 35.—HARDNESS (BHN) OF CU-AL-SI ALLOYS (12)

% Al	% Si	t, °C	20	250	350	450	550	650	750	850	900
2.54	2.59		59.4	51	48.4	40.2	32.4	20	15	10.6	
5.61	1.31		34.4	25.8	23.6	29.4	26.1	28	17.2	14.5	6.3

## LITERATURE

(For a key to the periodicals see end of volume)

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## AG, AU, HG, IR, OS, PD, PT, RH, RU, AND THEIR ALLOYS

THOMAS K. ROSE

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TABLE 1.—MECHANICAL PROPERTIES

Ag												
(D <sub>d</sub> ) (2, 6, 14, 18, 50, 74, 101)					(A,R)		BHN...	25	38	51	68	
t, °C....	-252	-182	15	100	200	(24)		UTS...	8.5	10.5	15	30
UTS....	64	53	31	23	18.5			El.....	31	12	4	4
(DA)	t,° C..	15	100	150	200	250	300	350	400	460		
(2, 48, 101)	UTS..	17	16	13.6	11.4	8.9	7.1	6.0	5.2	4.8		
Trt		UTS		YP	PL	El <sub>a</sub>		RA	Lit.			
G <sub>s</sub> .....		10.8		2.4	0.74	41		37.7	(87, 91)			
G <sub>m</sub> .....		11.5		3.3	1.8	59.5		66.7				
Trt		UBM*		No. B*	UWB*	IS†		YPC	Lit.			
G <sub>s</sub> .....		1.91		11.8	30.4			2.4	(87)			
G <sub>m</sub> .....		1.99		17.1	53.9	2.74		1.9				
		Trt		$-100\frac{\Delta l}{l_0}$		5	10	20	40	Lit.		
CS	{	G <sub>s</sub> .....		5.8		10.2	18.7	33.9	(87)			
		G <sub>m</sub> .....		6.3		11.5	20.5	35.3				
Trt.....		G <sub>m</sub>		G <sub>s</sub>	R <sub>d</sub>	MSH v. Ag-Au						
ScH†.....		7-12		8	48							
Lit.....		(78, 87)										
A at:		125°	150°	300°	460°	105°	Lit.					
For:		30 m	1 h	30 m	30 m	120 h	(78)					
ScH†.....		31	16	14.5	7	16.5						
(G) BHN§ = 30 (24.6-42) (15, 24, 29, 39, 43, 45, 49, 87).												
(R, A) BHN§ = 30 (24.4-37) (15, 24, 42, 85).												
(R <sub>d</sub> ) BHN = 89.7 (24).												
t, °C.....	-38	0	40	80	140	Lit.						
BHN  .....	37.5	36.0	34.6	33.5	32.0	(29)						
t, °C.....					18	200	Lit.					
BHN§.....					29.3	27.1	(39)					

Ag-Al; for BHN v. Fig. 2

TABLE 1.—MECHANICAL PROPERTIES.—(Continued)

Ag-Au						
% Au.....	0	15	30	50	Lit.	
MSH.....	50.8	72.8	90.9	97.4	(44)	
For LCH v. Fig. 5.						
Ag-Cu; v. also Fig. 3 for BHN						
Ag, 92.5; Cu, 7.5 (standard or sterling silver) ( 87)						
Trt		UTS	YP	PL	El <sub>a</sub>	RA
G <sub>s</sub> .....		22.2	12.8	7.4	41	54.6
G <sub>m</sub> .....		17.2	13.4	6.2	6.75	15.8
Trt		UBM*	No. B*	UWB*	IS†	YP <sub>C</sub>
G <sub>s</sub> .....		3.46	10.8	59.4	1.88	12.3
G <sub>m</sub> .....		3.37	3.4		2.21	20.2
CS {	Trt $\searrow$ $-100\frac{\Delta l}{l_0}$		5	10	20	40
	G <sub>s</sub> .....		19.8	25.7	37.5	49.9
	G <sub>m</sub> .....		27.4	33.2	41.1	53.5
Trt		ScH	BHN¶	Lit.	(D <sub>d</sub> )	
G <sub>s</sub> .....		18	60	(87)	UTS = 43	
G <sub>m</sub> .....		21-24	63		(74)	
G <sub>m</sub> R (1.125 in. to b in. thick) (87)						
10 <sup>3</sup> b.....		500	250	125	53	42
ScH†.....		54	60	68		83
BHN¶.....		135	157	170	181	183
Ag, 92.5; Cu, 5.75; Cd, 1.75 (87)						
Trt		ScH		BHN¶		
G <sub>s</sub> .....		22		73		
G <sub>m</sub> .....		23		74		
CS {	Trt $\searrow$ $-100\frac{\Delta l}{l_0}$		5	10	20	40
	G <sub>s</sub> .....		17.4	22.7	37.8	51.7
	G <sub>m</sub> .....		18.3	23.8	35.8	60.1



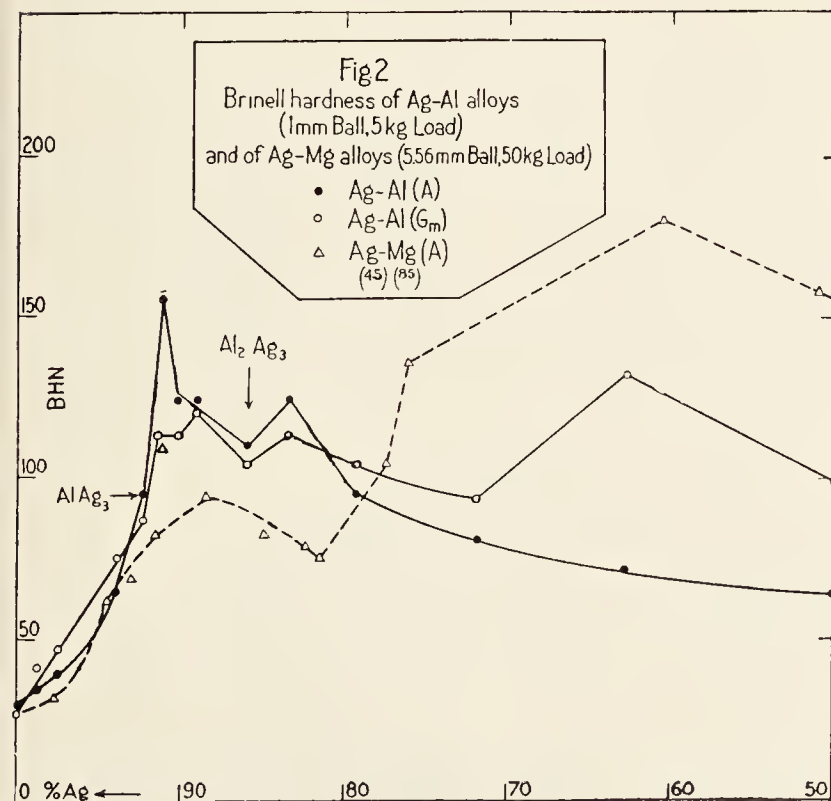
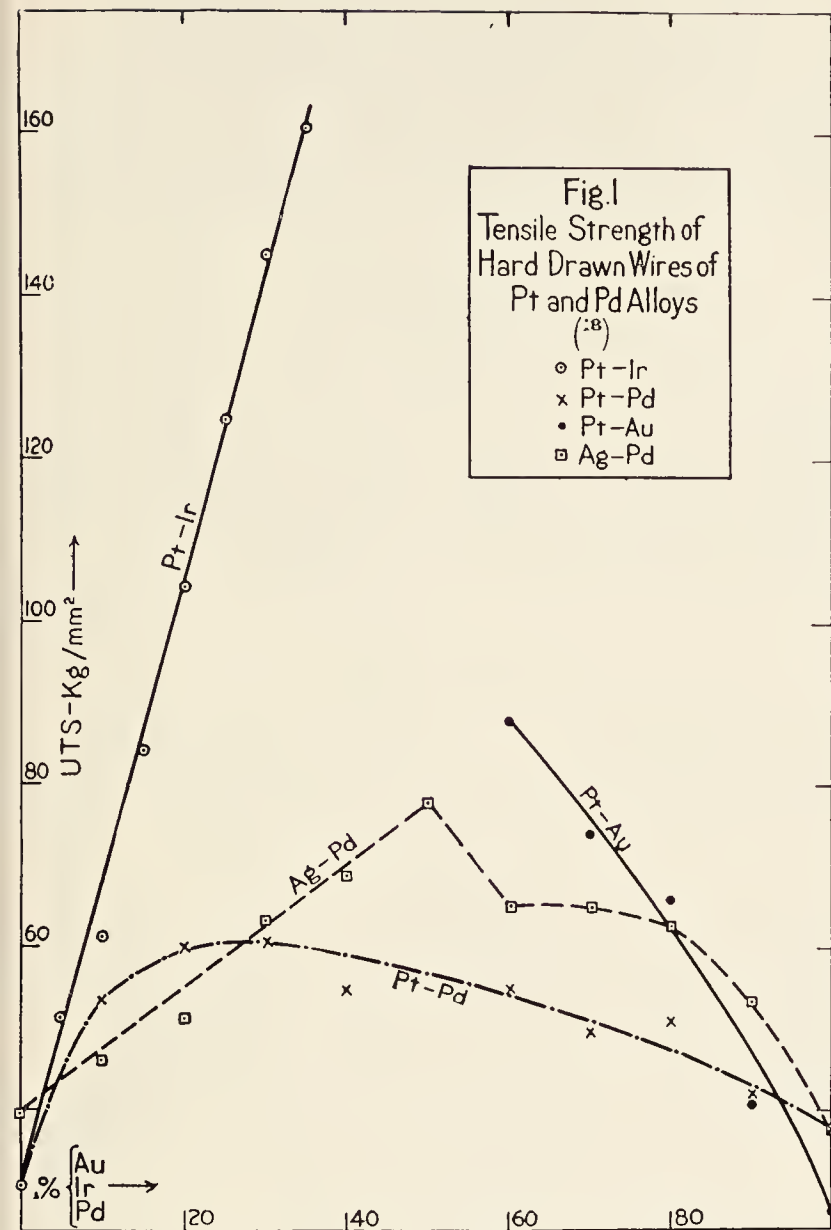


TABLE 1.—MECHANICAL PROPERTIES.—(Continued)

 $G_m R$  (1.125 in. to b in. thick)

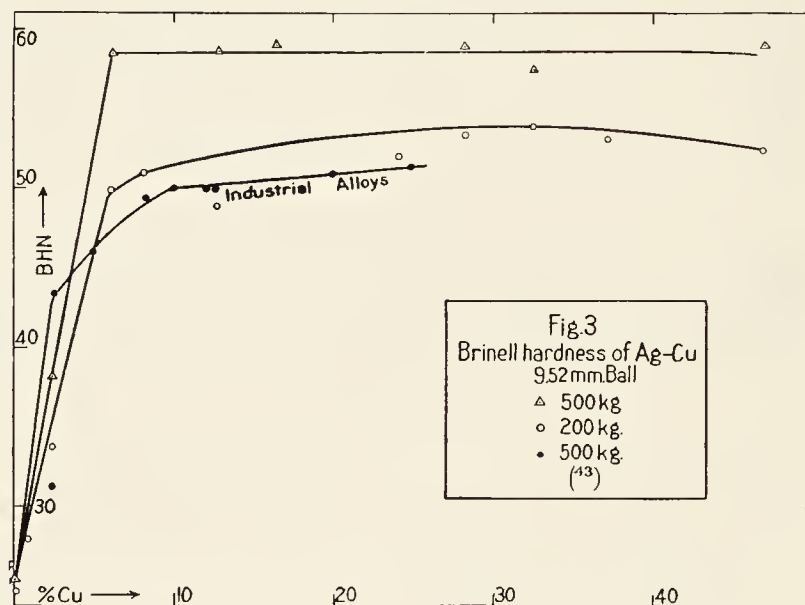
$10^3 b$ .....	500	250	125	53	42
$ScH \dagger$ .....	53	57	37		75
$BHN \ddagger$ .....	134	150	164	173	173

Trt	UTS	YP	PL	$El_a$	RA
$G_s$ .....	20.7	9.9	3.6	4.0	49.7
$G_m$ .....	13.3	8.9	2.5	9.0	21.4

Trt	UBM*	No. B*	UWB*	IS†	YPC
$G_s$ .....	3.25	12.1	59.4	2.40	10.7
$G_m$ .....	3.58	25.1	138.3	2.74	11.0

Ag-Cu (G),  $10 \times BHN$  (9.5 mm Ball); Effect of Rate of Cooling (42)

Load	% Cu	5.2	13.0	23.0	28.2	33.0	50
100 kg.....		415 A	607 C <sub>q</sub>	600 C <sub>q</sub>	1169 C <sub>q</sub>	520 C <sub>s</sub>	572 C <sub>s</sub>
500 kg.....		356 A	763 C <sub>q</sub>	945 C <sub>q</sub>	618 C <sub>r</sub>	425 A	1005 C <sub>q</sub>



Trt	% Cu	7.5	8.3	10.0	16.5	20.0	28.0	Lit.
$ScH \dagger$ {	$R_d$ .....	56	71	73	75	76	77	(78)
	A.....	20	23	23.5	28.5	31	28.5	

Ag, 83.5; Cu, 16.5 (G),  $BHN = 68$ ; (10 mm, 1000 kg) (24)Ag-Cd; Ag-Mg;  $Ag_2Te$ 

Compound	BHN	Lit.
Ag-Cd.....	74.1	(45)
Ag-Mg v. also Fig. 2.....	68-76	
$Ag_2Te$ .....	25.8	

Ag-Pd; for UTS v. Fig. 1

$Ag_3Sn$ (10 mm ball) {	$P$ , kg.....	50	100	200	Lit.
	$BHN$ .....	47.8	62.5	73.1	(45)

UCS of Ag-Sn amalgams v. (19).

TABLE 1.—MECHANICAL PROPERTIES.—(Continued)

## Au, Pure

(D <sub>d</sub> ) (2, 6, 14, 101)					Trt	UTS	Lit.	
<i>t</i> , °C.....	−182	15	100	200	DA.....	10	(101)	
UTS.....	31.7	25	15.8	13.1	G.....	11.0	(2, 73)	
Trt.....	G	R <sub>d</sub>	RA, 107°	RA, 115°	RA, 122°	RA, 129°	RA, 150°	Lit.
SeH*†.....	5	30	24	17	8	7	6	(79, 80)

(G<sub>m</sub>) *El<sub>b</sub>* = 30.8 (73); for *LCH*, *v.* Fig. 5.(RA) *BHN* = 25 (13.6-33) (15, 24, 42, 46, 64); (R<sub>d</sub>) *LCH* = 61 (79).Au (impure) (G<sub>m</sub>) (73); *v.* also Fig. 5 for *LCH*

100 × %.....	20 Ag	19 Al	21 Bi	20 Cd	19 Cu	29 In
UTS.....	11.2	13.9	0.8	10.8	12.9	12.55
<i>El<sub>b</sub></i> .....	33.3	25.5	ca. 0	44.0	43.5	26.5
RA.....		46	0			72

100 × %.....	20 K	20 Li	20 Mn	24 Pb	20 Pd	20 Rh
UTS.....	<0.8	13.9	12.55	6.5	11.2	12.2
<i>El<sub>b</sub></i> .....	ca. 0	21.0	29.7	4.9	32.6	25.0
RA.....	0	60		ca. 0	75	

100 × %.....	20 Sb	20 Sn	19 Te	19 Tl	20 Zn	20 Zr
UTS.....	9.0	9.75	6.1	9.75	11.8	
<i>El<sub>b</sub></i> .....		12.3	ca. 0	8.6	28.4	12
RA.....	54		0	15	74	

## Au-Ag

% Ag.....	0	15	35	50	Lit.
MSH.....	44.5	78.1	88.7	97.4	(44)

For effect on scleroscope hardness of small amounts of Ag, Cu, H, *v.* (79).

## ScH (79)

Trt		R <sub>d</sub>	A 250°	A 450°
% Ag				
8.3		41	41	7
25.0		49	43	10
50.0		47		10
62.5		49	39	11.5

## Au-Ag-Cu (nuggets) (104)

% composition			<i>BHN</i>		
Au	Ag	Cu	Natural	(A)	(Pr)
92.46	6.82	0.23	33.0	19.2	
89.25	9.30	0.50	44.5	19.5	38-42
79.3	17.3	3.4	34.0	20.8	

## Au-Cd

For *BHN v.* Fig. 2, p. 549.

## Au-Cu

% Cu....	0	10	20	30	40	50	60	70	80	90	Lit.
IS**.....	11.5††	16.5	2	3	4.5	9.5	8	11.5	9.5	7	(64)
% Cu.....	0	15				35		50			Lit.
MSH.....	44.5		65.5			93.0		107.1			(44)

TABLE 1.—MECHANICAL PROPERTIES.—(Continued)

(4, 35, 75)			ScH (78)		
% Cu	UTS	Trt	G	R <sub>d</sub>	A
8.3	28.3	G	23	65	23
10.0	45.8	D <sub>a</sub>		69	29
16.6	35.1	G	For <i>BHN</i> ; <i>v.</i> Fig. 4		

## Au-Cu-Ag (99)

% composition		Trt	G	AQ	R <sub>d</sub>	G	AQ	R <sub>d</sub>
Cu	Ag		ScH†			<i>BHN</i>		
27.5	10		48	44	75	160		
25	25		66	48	73	205	159	
40	10		36		75	123		245

## Au-Cu-X (G) (99)

% composition		ScH	<i>BHN</i>
Au, 50; Cu, 48; Al, 2.....		20	88
Au, 50; Cu, 48; Ni, 2.....		22	91

Au, 53; Cu, 30; Ag, 12, (D<sub>a</sub>) *UTS* = 192.0 (9)

## Au-Ni (42)

% Ni	Trt	<i>BHN</i> ††	% Ni	Trt	<i>BHN</i> ††
0	C <sub>s</sub>	13.6	23.5	C <sub>q</sub>	235
9.5	C <sub>s</sub>	84.0	23.5	Q, A 72 h	140
20	C <sub>s</sub>	191.5	30	C <sub>s</sub>	183
23.5	C <sub>s</sub>	205	40	C <sub>s</sub>	159
23.5	C <sub>r</sub>	150			

## Au-Pt

For *UTS v.* Fig. 1.

## Cu-Au-X (80)

Trt		G	R <sub>d</sub>	A 650°	Trt		G	R <sub>d</sub>	A 650°
% Comp.		ScH†			% Comp.		ScH†		
Au	Ag				Au	Al			
20	50	36	86		40	4	22	90	
25	20	31	81		40	6	26		
25	15	29	78						
25	10	25	71		Au	Ni			
25	9§§	28	72		25	5	22	66	
40	30	65			25	2.5	23	63	
40	10	34	94	46	30	5	26	70	
40	0	21	84	38	40	2.5	23	72	
					40	5	25	83	43
					40	10	32	93	40

## Hg-X (amalgams)

Effect of time on hardness||| (90)

Hours after mixing	<i>BHN</i> ¶¶			
	92.5 % Cd	95.0 % Pb	94.8 % Sn	75.0 % Zn
0.25	23.9	12.1	15.4	25.5
6			21.3	
24	31.2	13.6	22.6	76.0
48	31.2	13.6	23.2	76.0



TABLE 1.—MECHANICAL PROPERTIES.—(Continued)

Hardness of Tl-Hg

BHN\*\*\* (68)

Load	50 kg	100 kg
% Hg		
0	1.57	
1	3.19	
3	4.15	4.85
5	4.99	5.12
7	3.60	3.85
9	3.66	3.93
11	3.18	3.36

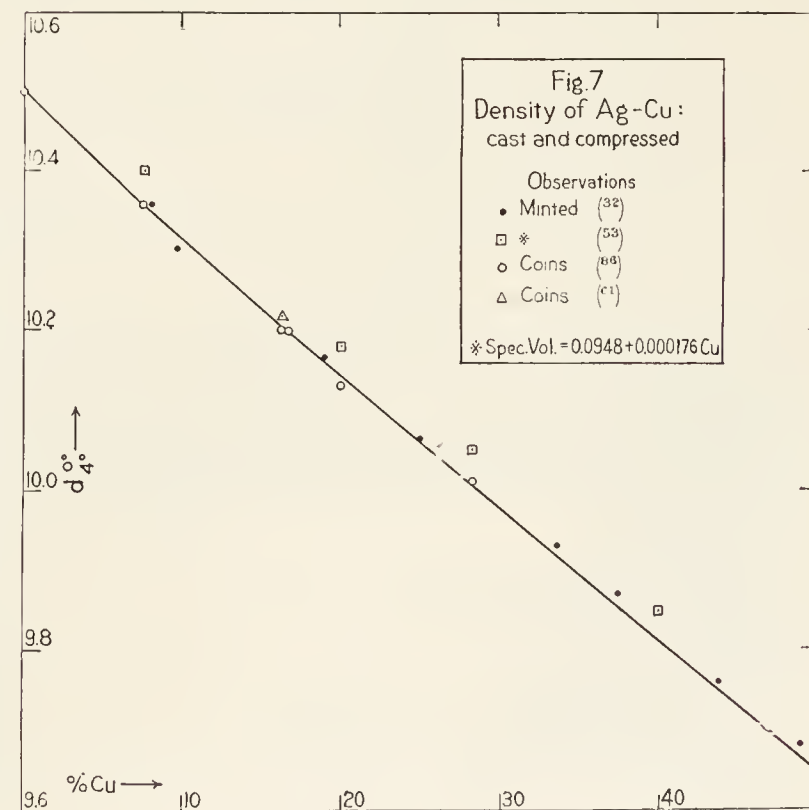
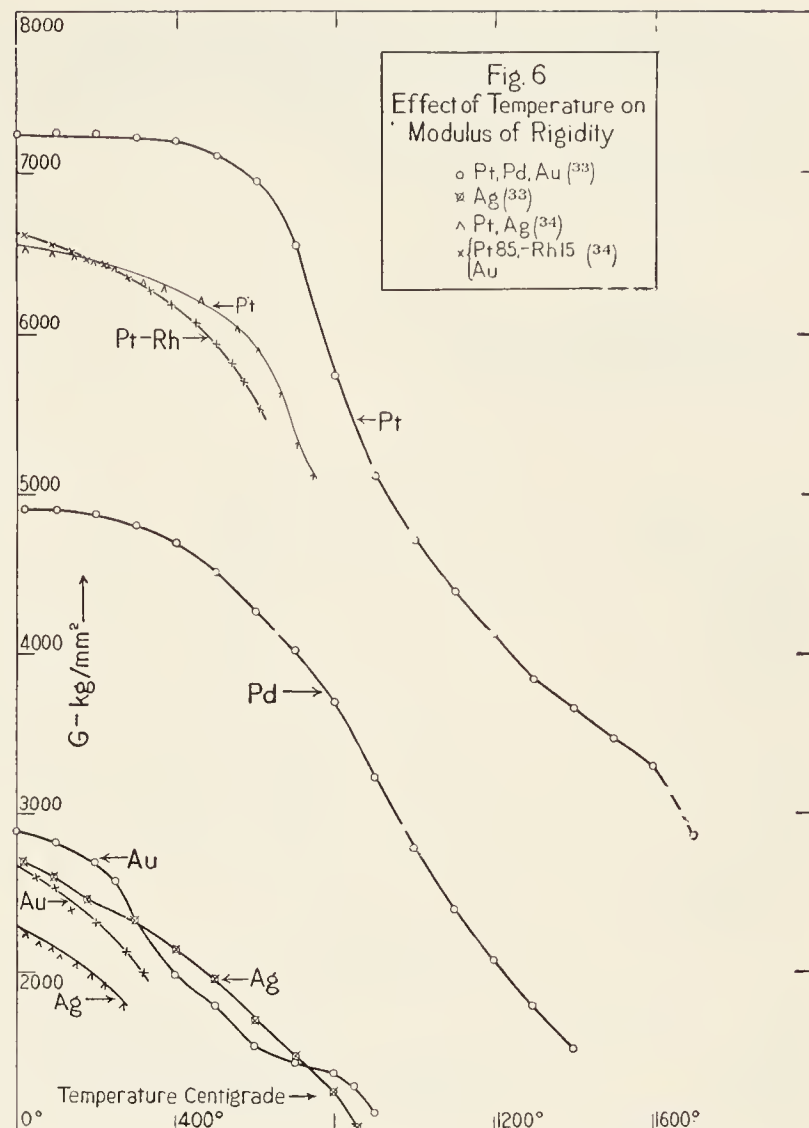
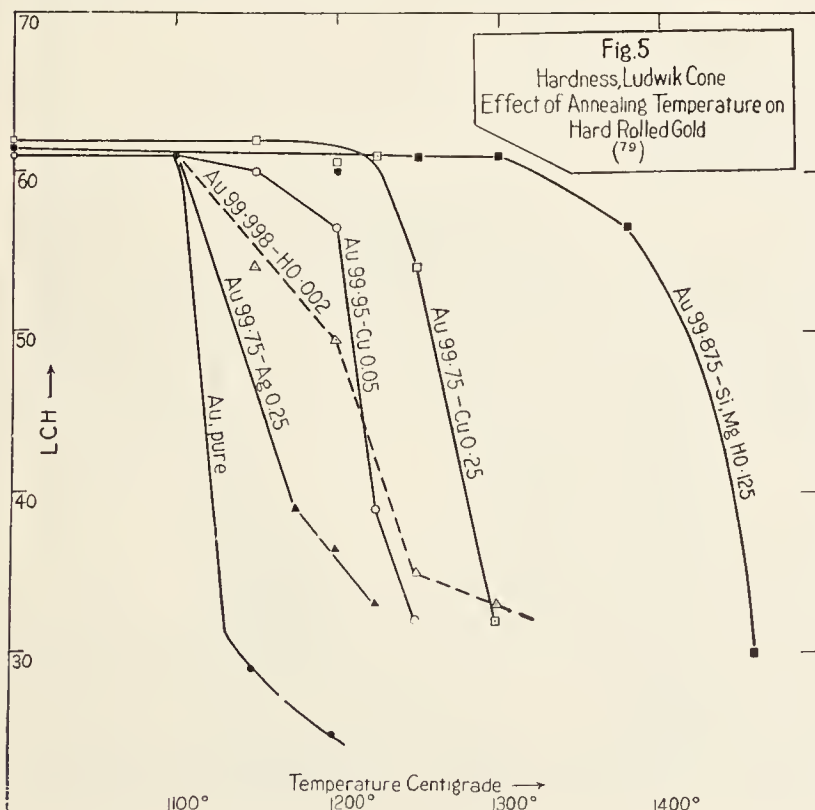
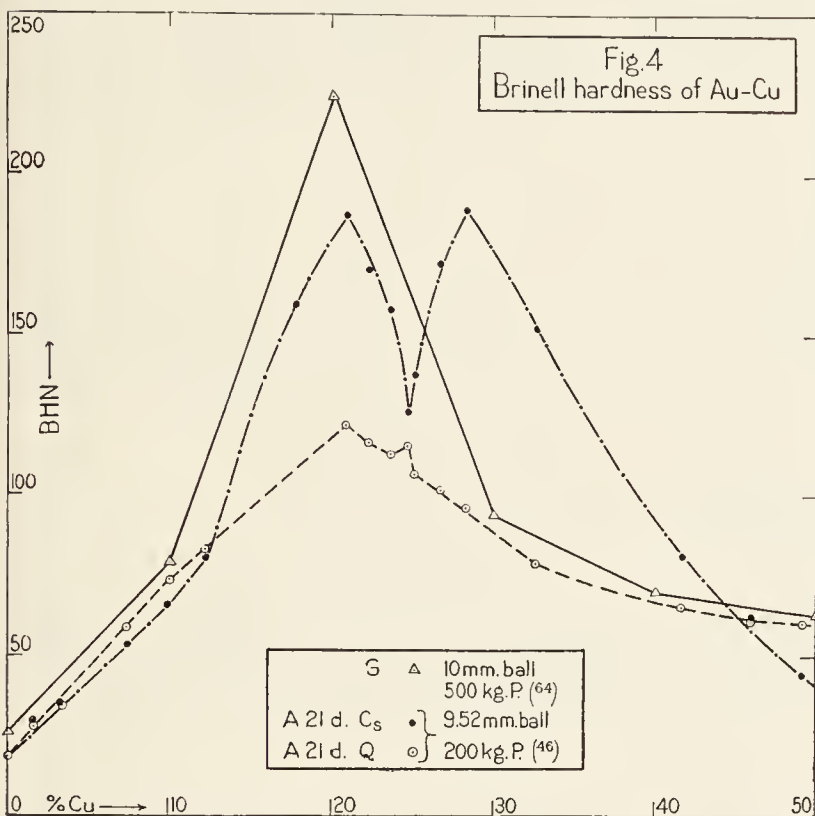


TABLE 1.—MECHANICAL PROPERTIES.—(Continued)

For effect of time on hardness of other, less hard amalgams of Cd, Pb, Sn, Zn; also for hardness of amalgams of Cu (*BHN*, max. at 35% Cu) and Ag-Sn amalgams (*BHN*, max. at 60% Ag, 22% Sn), *v.* (90).

For *UCS* of Ag-Sn amalgams, *v.* (19).

**Ir**

*BHN* of cast Ir = 172 (10).

**Pd**

*UTS* of hard drawn wire = 38 (18); = 27.4 (9).

*BHN* of cast Pd = 49 (10).

For *UTS* of Pd-Ag, Pd-Pt, *v.* Fig. 1.

**Pt**

*BHN* (103)

Source or Trt	Load, kg	100	200
Heraeus.....		31	34
Russian.....		40	46
Pure (Hm).....		60	64
Pure (A).....		24	26

*UTS* of *D<sub>a</sub>* wire = 34 (9, 18, 47, 56, 101); of A wire = 24.5 (9, 47, 101).

Trt.....	G	A 300°	A 650°	Lit.
<i>BHN</i> .....	117	121	46	(10)

Nuggets: Natural state, *BHN* = 105–108; annealed, *BHN* = 86–88 (104).

**Pt-Ir (*BHN*)**

Trt	% Ir	1	5	10†††	15	20	25	30	Lit.
<i>H<sub>wk</sub></i> .....	117	170	220	280	330	370	400		(10)
A 1150°.....	47†††	110†††	150	190	230	270	310		

Load, kg	100	200	Lit.
% Ir			
1	25	27	(103)
2.5	32	35	

For *UTS* of Pt-Ir, Pt-Pd, *v.* Fig. 1.

**Pt-Os**

Os has about 2.5 times the hardening effect of Ir (10).

**Pt-Rh**

Pt, 90; Rh, 10 (A); *BHN* = 90 (10).

**Rh**

*BHN* of cast Rh = 139 (10).

**Ru**

*BHN* of impure cast Ru = 220 (10).

\* Sankey machine: Test piece, 3/8 in. diam; length between jaws = 1.75 in.; angle of bending = 45 3/4 deg. *No. B* = Number of bends.

† Charpy machine: Standard 10 × 10 mm specimen, 40 mm span, 5 mm keyhole notch.

‡ Magnifier hammer.

§ *BHN* determined with 10 mm ball, 400–100 kg load, or with smaller ball and equivalent loads. In all cases loads are less than the standard *P* = 30 D<sub>2</sub>.

|| 10 mm; 500 kg.

¶ 3.96 mm, 210 kg.

\*\* Guillery machine.

†† Test piece bent, no sign of fracture.

‡‡ 9.52 mm ball, 500 kg load.

§§ Contains 1% Ni.

||| At 20°C.

¶¶ 2 mm ball, 8.7 kg load.

\*\*\* 10 mm ball, *BHN* = load ÷ area of impression.

††† 10% Ir (G) *BHN* = 170.

‡‡‡ A 1000°.

TABLE 2.—ELASTIC PROPERTIES

Ag; *v.* also Fig. 6

Trt....	<i>D<sub>a</sub></i>	DA	Lit.	Trt = D	Lit.
<i>t</i> , °C....	15	100	200	15	(20, 21, 59, 93, 95, 101)
<i>E</i> .....	7900	7274	6374	7300	(21, 27, 28, 33, 38, 41, 63, 82, 89, 94)

$\lambda = 0.37$  (DA) (1, 7, 22, 34, 47, 81, 83, 93);  $\lambda = 0.39$  (*D<sub>a</sub>*) (93).

Ag, 66.6; Pt, 33.3 (93, 95)

(*D<sub>a</sub>*): *E* = 10000, *G* = 3023. (A): *E* = 10510, *G* = 3699,  $\lambda = 0.42$ .

Au; *v.* also Fig. 6

Trt....	G	<i>D<sub>a</sub></i>	A	Lit.	Trt = D	Lit.
<i>t</i> , °C....			15	100	200	(20, 21, 59, 60, 93, 96, 101)
<i>E</i> .....	7580	8000*	5584	5408	5482	(21, 27, 28, 33, 38, 41, 89, 96)

$\lambda = 0.42$  (34, 47).

**Ir**

*E* = 52700 (*D<sub>a</sub>*) (20).

Pd; *v.* also Fig. 6

Trt....	<i>D<sub>a</sub></i>	A	Lit.	G	Lit.
<i>E</i> .....	12000†	9750	(20, 21, 37, 82, 98, 101, 102)	4500	(21, 37, 38, 82, 101)

$\lambda = 0.39$  (33, 47).

Pd saturated with H<sub>2</sub>

*E* = 13.2% (10–21%) < *E* for pure Pd. *G* = 12.7% (10.0–16.5%) < *G* for pure Pd (37).

Pt; *v.* also Fig. 6

Trt	<i>D<sub>a</sub></i>	A	Lit.	Trt = D	Lit.
<i>t</i> , °C....		ca. 15	100	200	(20, 22, 55, 59, 82, 93, 95, 101, 102)
<i>E</i> .....	17000‡	15200§	14178	12964	(21, 27, 28, 38, 41, 63, 82, 94)

$\lambda = 0.38$  (22, 33, 47).

Pt, 85; Rh, 15

*G* = 6600 (28); *v.* also Fig. 6.

**Rh**

*E* = 30000 (*D<sub>a</sub>*) (20).

\* (7780–8630).

† (10000–14300).

‡ (16030–17900).

§ (14900–15600).

TABLE 3.—EFFECT OF TEMPERATURE ON ELASTIC PROPERTIES

See also Fig. 6

Metal	Ag	Au	Pd	Pt	Rh	Lit.
<i>E<sub>0 abs</sub>/E<sub>0°C</sub></i> .....	1.37	1.32	1.27	1.27	1.18	(55)

Metal	100 $\frac{E_0 - E_{100}}{E_0}$	Lit.	100 $\frac{G_0 - G_{100}}{G_0}$	Lit.	100 $\frac{\lambda_0 - \lambda_{100}}{\lambda_0}$	Lit.
Ag	3.97	(33)	7	(20, 27, 28, 33, 38)	14	(7, 33)
	–Δ <i>E</i> for 100° = 7.65% (82)					
Au	3.6	(33, 97, 101)	3	(27, 28, 33, 38, 82)	25	(33)
Ir			4	(20)		
Pd	2	(33, 82)	3	(20, 37, 38, 82, 101)		
Pt	–Δ <i>E</i> for 100° = 0.73%	(82)	1	(27, 28, 38, 82)	5.5	(33)
				(0.14–1.78)		
Rh			3.7	(20, 21, 22, 82, 82)		



TABLE 4.—COMPRESSIBILITY OF AG-AU (4)

For compressibility of pure metals, *v. vol. III.*

100 × % Ag.....	0	116	586	1415	2317	3399	4773	6771	8555	9649
10 <sup>8</sup> χ.....	155	140	160	126	111	113	113	130	134	146

$$\chi = \frac{1}{V_0} \frac{\Delta V}{\Delta p} \text{ where } \Delta p = 1 \text{ atm.}$$

TABLE 5.—SPECIFIC VOLUME OF ALLOYS

System	10 <sup>5</sup> a*	10 <sup>7</sup> b*	Range† of observations, %	Max. error, %	Inter-section‡	Lit.
Ag-Au.....	9500	-4309	0-100	+0.2		(53)
Ag-Bi.....	9550	630	0-100	-0.4		(53)
Ag-Cd.....	9700	1034	17-46	-0.4		(54)
Ag-Cu.....	9480	1760	0-100	+0.7		(53)
Ag-Pb.....	9551	-760	0-100	+0.7		(53)
Ag-Pd.....	9533 9244	-1386 -844	0-40 60-100	+0.7 ±0.2	52	(58)§
Au-Cu.....	5191	6050	0-100	+0.7		(53)
Au-Pb.....	5191	3599	0-100	-1.0		(53, 57)
Au-Sn.....	5191	8520	0-100	-1.5		(53)
Hg-In.....	7385	5830	0.4-1.9	±0.04		(70)§
Hg-Pb.....	7368	1422	0-100	-1.0		(53)
Hg-Sn.....	7368 7368	6345 6212	0-100 0-100	-0.9 +0.8		(53) (10, 26, 40)§
Hg-Tl.....	7368 7674	1238 772	0-43 80-100	±0.1 -0.2	66	(66, 70) (68)§
Hg-Zn.....	7368 7006	6556 7212	0-48 60-100	+0.5 +0.1	56	(12, 54)§
Ir-Pt.....	4461	190	0-100	±0.2		(53)

\* Specific vol. = a + bx, where x = % by weight of second metal in formula of the alloy system.

† Per cent of second metal.

‡ Where the results are best represented by two straight lines, the point of intersection is given.

§ Line determined from data given in literature reference.

TABLE 6.—SPECIFIC GRAVITIES OF ALLOYS

For specific gravities of pure metals, *v. p. 456*

% composition	Treatment, description	Test temp., °C	Ref. temp., °C	d*	Lit.
Ag-Au.....	<i>v. Fig. 8 and Table 5</i>				
Ag, 67.5; Bi, 32.5..	G } <i>v. also Table 5</i>	15.1	15.1	10.323	(26)
51 49		13.2	13.2	10.197	(26)
Ag-Cd.....	<i>v. Table 5</i>				
Ag, 92.5; Cu, 7.5...	Rd	15	4	10.3485	(78)
	A 700°	15	4	10.2469	(78)
	Coin	13		10.37	(77, 86)
Ag, 83.5; Cu, 16.5	G	18.5	18.5	9.99932	(61)
( <i>v. also Fig. 7 and Table 5</i> ).	A	18.5	18.5	10.00206	
	AR	18.5	18.5	10.20244	
	ARA	18.5	18.5	10.20251	
	ARAR	18.5	18.5	10.20759	
	ARARA	18.5	18.5	10.21648	
	Same, struck	18.5	18.5	10.21636	
	French coin	15		10.16-10.20	(86)
Ag, 80.0; Cu, 20.0.	Canadian coin	15		10.13	(86)
Ag, 71.9; Cu, 28.1	Molten			9.0554	(71)
	Netherlands gulden			10.011	(86)
Ag, 50.0; Cu, 50.0.	English coin	13		9.640-9.642	(86)
Ag, 50; Cu, 41; Ni, 9	English coin	13		9.60-9.61	(86)

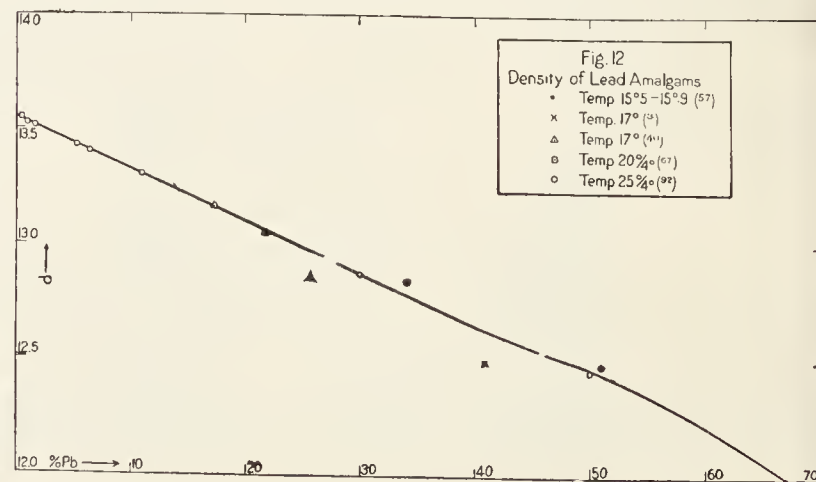
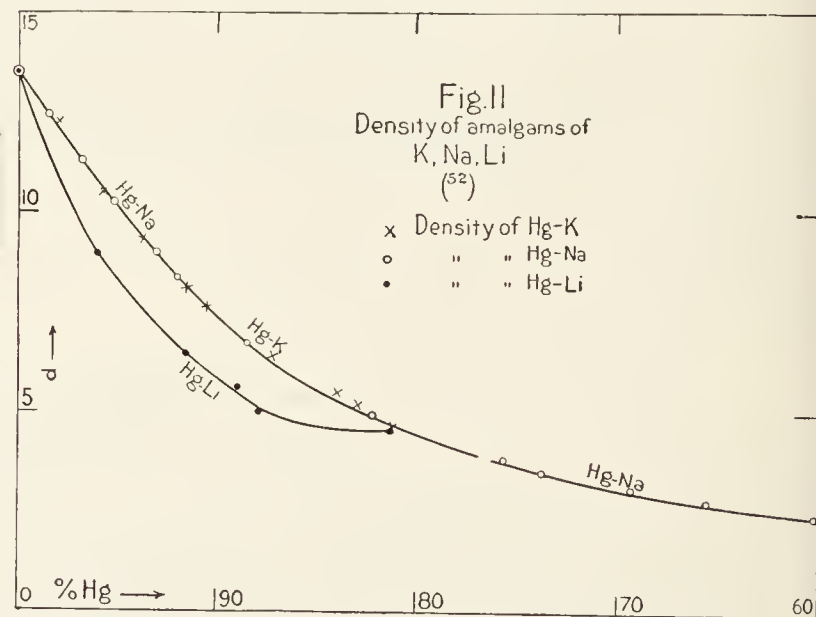
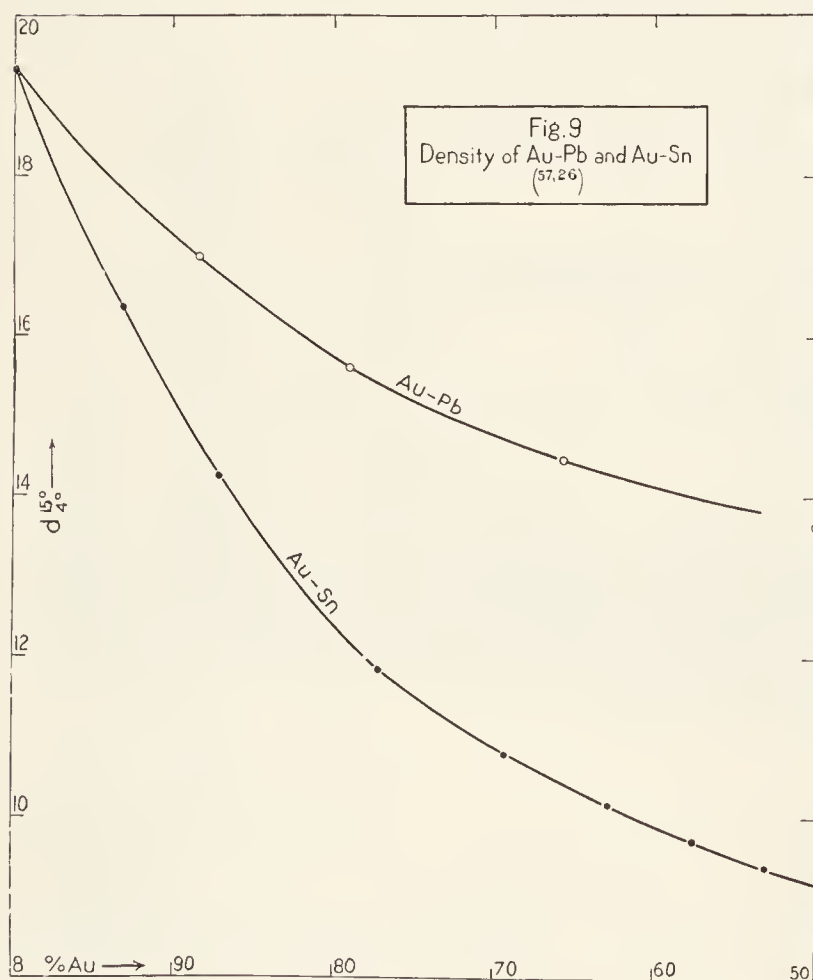
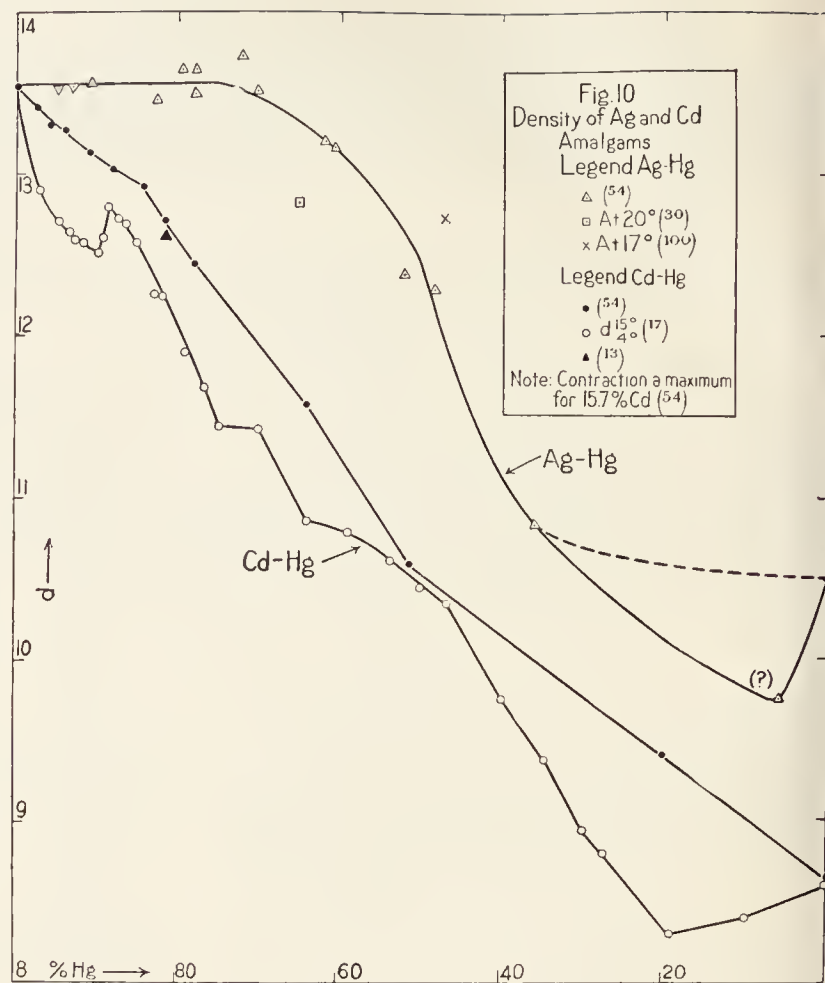
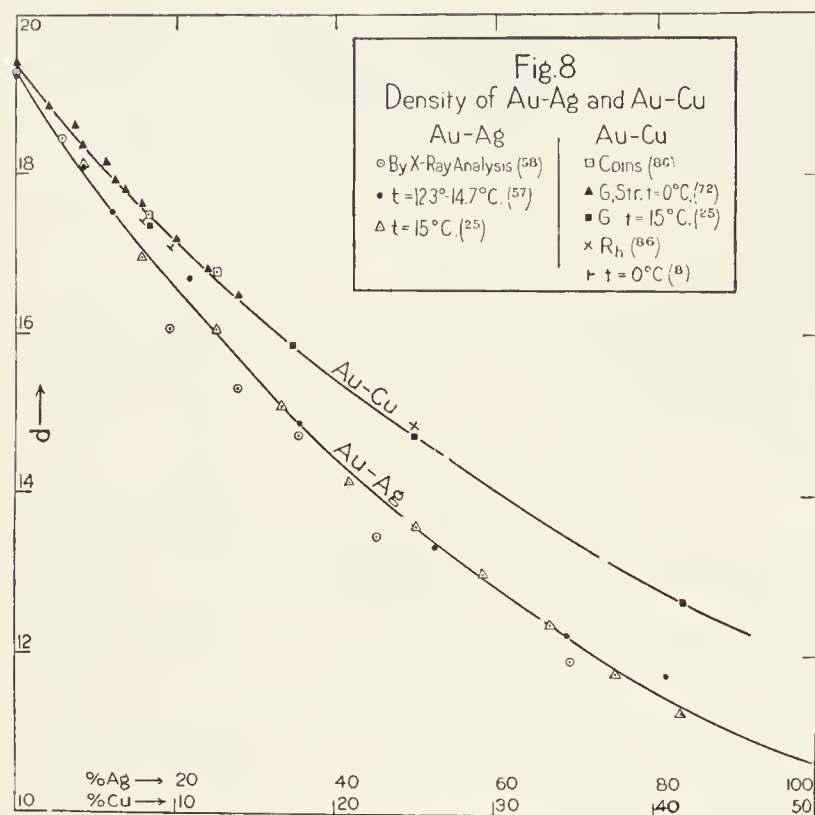
TABLE 6.—SPECIFIC GRAVITIES OF ALLOYS.—(Continued)

For specific gravities of pure metals, *v. p. 456*

% composition	Treatment, description	Test temp., °C	Ref. temp., °C	d*	Lit.
Ag, 67.6; Pb, 32.4..	G } <i>v. also Table 5</i>	13.5		10.800	(57)
51.1 48.9		13.8		10.925	
Ag-Pd	<i>v. Table 5</i>				
Ag, 100; Sb, 0.....	All alloys show expansion, max. being at 25.4 % Sb			10.49	(54)
85.4 14.6				10.017	
74.6 25.4				9.682	
69.5 30.5				9.356	
Ag, 78.8; Sn, 21.2..	G	14.8		9.953	(26)
Ag, 73.16; Sn, 26.84	Filings	25	4	9.80	(16, 38, 51)
(Ag <sub>3</sub> Sn) Contraction of sp. vol. = 5 % (19).	Same, A 100°	25	4	9.89	(36)
	In mass	0	4	9.8690	(51)
	Filings	0	4	9.7772	(51)
	Same, A 100°/2 h	0	4	9.8033	(51)
	Same, A 350°/5 h	0	4	9.8141	(51)
Ag, 70.8; Sn, 29.2..	Maximum contraction of specific vol.				(53)
Ag, 65; Sn, 35.....	G	12.9		9.507	(26)
Ag, 54.7; Zn, 45.3..	G			8.744	(54)
Au-Ag.....	<i>v. Fig. 8 and Table 5</i>				
Au Ag Cu	Struck in coin press 15 carat gold ware†			17.14	(86)
87.5 7.5 5.0				13.22-14.08	(86)
62.5 .....	G	16		14.844	(26)
Au, 65.4; Bi, 34.6..	G	16		14.844	(26)
Au, 91.6; Cu, 8.3..	British coin	15		17.48	(8, 76, 86)
	Scandinavian coin	0	4	17.1711	(8)
	Egyptian coin			16.794	(86)
	<i>v. also Fig. 8 and Table 5</i>				
Au-Pb and Au-Sn...	<i>v. Fig. 9 and Table 5</i>				
Hg-Ag.....	<i>v. Fig. 10 and (19)</i>				
Hg, 67.1; Au, 31.9..				15.412	(13)
Hg, 32.5; Bi, 67.5..				10.45	(13)
Hg-Cd.....	<i>v. Fig. 10</i>				
Hg-In.....	<i>v. Table 5</i>				
Hg-K, Hg-Li, Hg-Na.....	<i>v. Figs. 11 and 11a</i>				
Hg, 98.98; Pb, 1.02.	<i>v. also Table 5 and Fig. 12</i>	20	4	13.536	(67)
99.316 0.684		20	4	13.539	
99.603 0.397		20	4	13.541	
Hg, 99.79; Sn, 0.21.	<i>v. also Table 5</i>	20	4	13.529	(70)
99.70 0.30		20	4	13.519	
99.55 0.45		20	4	13.513	
Hg-Tl.....	<i>v. Table 5</i>				
Hg, 99.02; Zn, 0.980	<i>v. also Table 5</i>	25	4	13.4490	(12)
98.544 1.456		25	4	13.4054	
98.083 1.917		25	4	13.3628	
Ir-Pt.....	<i>v. Pt-Ir</i>				
Pd, 60.7; Pb, 39.3..					11.225 (3)
Pt, 95; Ir, 5.....	A, struck repeatedly	0	4	21.474	(81)
90 10		0	4	21.55	(81, 88)
85 15	A, struck AR	0	4	21.594	(81)
66.67 33.33		10		21.874	(81)
5 95	<i>v. also Table 5</i>	13		22.384	(81)
Pt, 48.5; Pb, 51.5..				15.736	(3)
Pt, 48.9; Tl, 51.1..	G, pulverized	14	14	15.65	(23)

\* If test temp. only is given, *d* is mass-density g/cm<sup>3</sup>; if ref. temp. is given, also *d* is specific gravity, referred to H<sub>2</sub>O at this ref. temp.

† See Index No. 635.





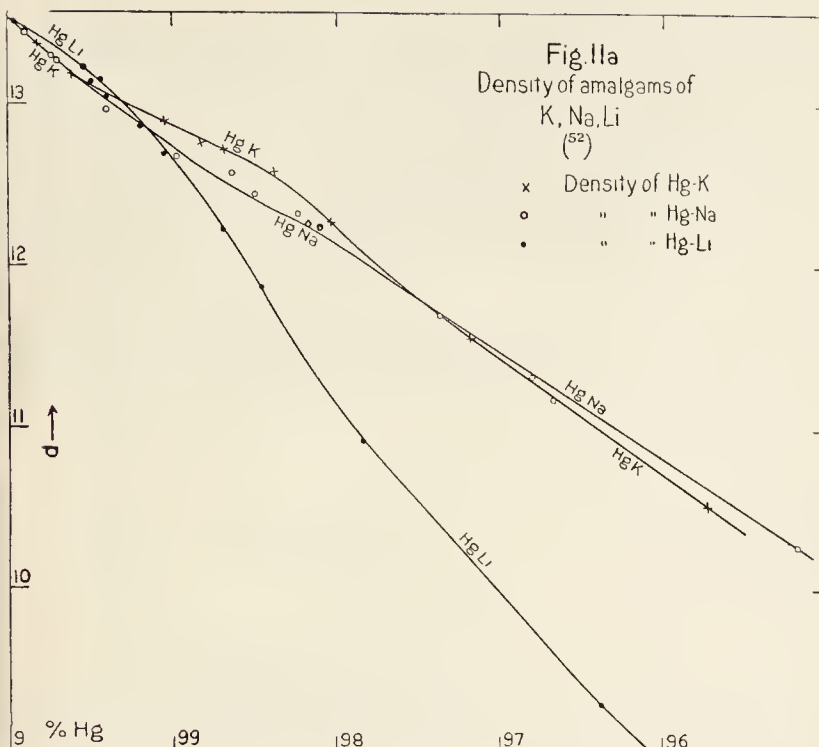


TABLE 7.—SURFACE TENSION OF AMALGAMS IN SATURATED WATER VAPOR AT *ca.* 18°C (84)  
For surface tensions of pure metals *v.* vol. III

Wt., %	$\alpha^2$ -cm <sup>2</sup>	$\gamma$ dyne/cm	Wt., %	$\alpha^2$ -cm <sup>2</sup>	$\gamma$ dyne/cm
Au, 0.0153	0.0656	435.5	Na, 0.00015	0.0655	435.5
0.0838	.0639	424.7	0.00067	.0639	424.2
0.122	.0639	424.7	0.00222	.0631	418.8
Ba, 0.00045	.0694	461.0	0.0490	.0596	393.3
0.0022	.0728	483.5	0.0670	.0594	391.3
0.0074	.0742	492.3	0.1240	.0591	386.4
Ca, 0.00020	.0659	436.5	Pb, 0.226	.0639	424.7
0.00100	.0689	458.0	0.936	.0626	415.9
0.00154	.0709	471.8	1.410	.0625	414.9
0.00274	.0713	473.7	Rb, 0.00157	.0654	434.5
0.00851	.0733	490.4	0.00313	.0651	432.5
Cd, 0.559	.0664	440.4	0.00778	.0555	368.8
1.204	.0675	446.3	0.04660	.0504	334.5
2.376	.068	447.2	Sn, 0.176	.0656	435.5
Cs, 0.00083	.0644	427.6	0.412	.0642	425.7
0.00160	.0607	403.1	0.868	.0644	425.7
0.00280	.0577	383.5	Sr, 0.00027	.0680	452.2
0.01310	.0505	335.4	0.00162	.0713	470.8
K, 0.00071	.0657	436.0	0.00372	.0725	481.6
0.00184	.0610	405.1	0.0153	.0753	500.2
0.00680	.0591	392.3	Tl, 0.0238	.0660	438.1
0.01350	.0586	388.4	0.0986	.0680	451.2
0.01500	.0577	382.5	0.490	.0683	453.1
Li, 0.0002	.0657	436.0	Zn, 0.661	.0660	437.1
0.0019	.0665	441.4	1.221	.0669	440.4
0.0056	.0678	450.2	1.750	.0671	440.4
0.0140	.0678	450.2			

TABLE 8.—ANNEALING AND QUENCHING TEMPERATURES

% composition	$t_0^*$	$t_{30}^\dagger$	Lit.
Ag.....	100	150	(78)
Ag‡.....	230	265	(5)
Au, 37.5.....	250	450	(79)
Cu, 7.5.....	230	550	(78)
Cu, 8.3.....	230	600	(78)
Cu, 10.0.....	230	650	(78)
Cu, 16.5.....	300	650	(78)
Cu, 20.0.....	300	700	(78)
Cu, 28.1.....	300	700	(78)
Au.....	80	120	(78)
Ag (etc.), 0.03‡.....	200	280	(5, 79)
Ag, 0.004.....	150	200	(79)
Ag, 0.25.....	150	225	(79)
Ag, 8.3.....	275	450	(79)
Ag, 25.0.....	275	450	(79)
Ag, 50.0.....	300	450	(79)
Cu, 0.01.....	140	150	(79)
Cu, 0.25.....	175	300	(79)
Cu, 8.3§.....	250	500	(78)
Cu, 10.0.....	300	700	(78)
H <sub>2</sub> , 0.002.....	150	300	(62, 79)
Pt.....	400	650	(10)
Ir, 0.1.....	450	1000	(10)
Ir, 10.....		1150	(10)
Ir, 20.....		1150	(10)
Ir, 25.....		1150	(10)

Au, 80; Cu, 20 to Au, 70; Cu, 30: Quench from 600° (46).

(Au + Ag), 80; Cu, 20 to (Au + Ag), 60; Cu, 40: Quench from 500° (99).

\*  $t_0$ , °C of beginning of softening.

†  $t_{30}$ , °C of completion of softening in 30 minutes.

‡ Pure commercial.

§ Softens completely at 300° in 384 hr.

## LITERATURE

(For key to the periodicals see end of volume)

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## GRAPHITE (*v. also* p. 468)

V. H. STOTT

Ultimate tensile strength = 2 kg/mm<sup>2</sup> (4, 5).  
Young's modulus = 836 kg/mm<sup>2</sup> (4, 5).

### SPECIFIC GRAVITY

$d_4^{20}$  = 2.25 to 2.26 (1).  
 $d_4^{15}$  = 2.255 (after compression to 5000 atm.) (3).  
 $d_4^{16}$  = 2.232 (after fusion in arc) (6).  
M. P. = 3500° ± 100°C (2).  
V. P. at triple point = 0.25 atm. (2).

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## MECHANICAL PROPERTIES OF AS, B, CA, CE, CO, CR, GE, IN, K, LA, MO, NA, PR, TA, TH, AND W AND THEIR ALLOYS, AND OF ALLOYS CONTAINING BA, GA, LI, MN, RB, SI, SR, TI AND V

C. H. DESCH

For specific gravity of the pure metals, *v. p.* 456; surface tension, *v. vol.* III; viscosity, *v. vol.* III; compressibility, *v. vol.* III.

TABLE 1.—TENSILE PROPERTIES OF CA, CO, MO, TA, TH AND W

Metal	Treatment	UTS	El	RA	Lit.
Ca	Cast.....	6.12*	6†		(19)
Co	Cast‡.....	24			(34)
	Annealed§.....	26			
	Drawn wire.....	68	5	8	
Mo	Drawn wire ( <i>v. also</i> Figs. 1, 2, 3).....	180–220			(15)
	Sheet.....	70	43		(68)
Ta	Hard drawn wire.....	93			(61)
Th	Drawn wire.....	56.3			(55)
W	Hammered.....	150	4	28	(16)
	Drawn wire.....	420			(32)
	Drawn to mm diam.:				(16)
	0.45	186			
	0.18	240			
	0.145	256	<i>v. also</i>		
	0.10	339	Fig. 4		
	0.028	411			
	Rolled sheet.....	335			
	Single crystal wires.....			100	

\* Probably too high due to impurity.

† On 5 cm.

‡ UCS = 87; YPC = 30 kg/mm<sup>2</sup>.

§ YPC = 39 kg/mm<sup>2</sup>.

|| YP just below UTS; PL = 46.

TABLE 2.—HARDNESS OF AS, B, CA, CE, CO, CR, GE, IN, K, LA, MO, NA AND PR

Metal	Treatment	BHN	Ball diam. mm	Load, kg	ScH	EP, kg/mm <sup>2</sup>	Lit.
As	Metallic.....	147	10	1000			(14)
B	Usually described as nearly as hard as diamond.						
Ca		42*	10	500	19–20		(5)
Ce		28.0	5	90	26 (rolled) 9 (fresh cut)		(27) (23)
Co	Cast.....	124 86	10 10	1600 1000			(34) (14)
	Electrolytic†.....	270–311					(44)
Cr		91	10	500			(14)
Ge	Between 6 and 6.5 on Mohs' scale of hardness.						(8)
In		1.0	10	50		3.1	(14, 39)
K		0.037	10	1.6		0.25	(14, 39)
La		37	10	500			(36)
Mo		147			12 (rod) 35 (sheet)		(68) (68)
Na		0.07	10	3.2		0.3	(14, 39)
Pr	Electrolytic‡.....	25	10	500			(71)

\* *v. also* (14).

† Probably contained H<sub>2</sub>.

‡ At least 99.7 % pure.



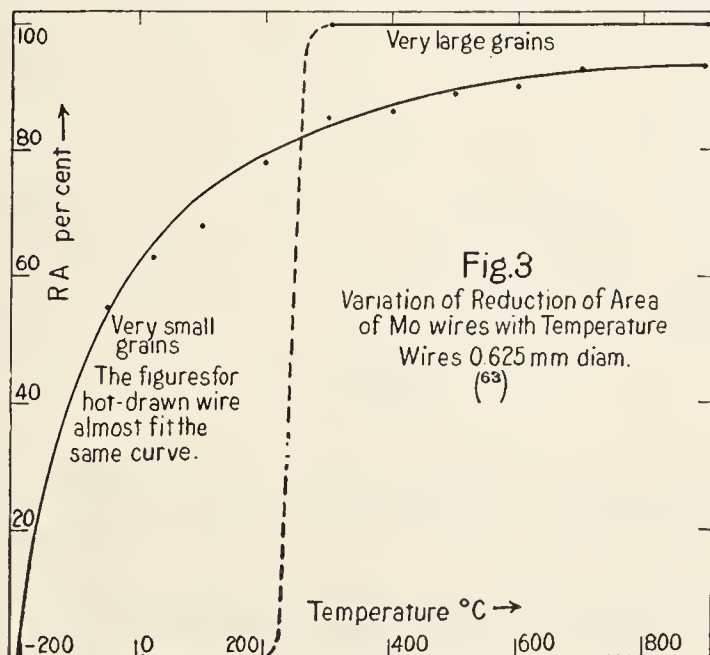
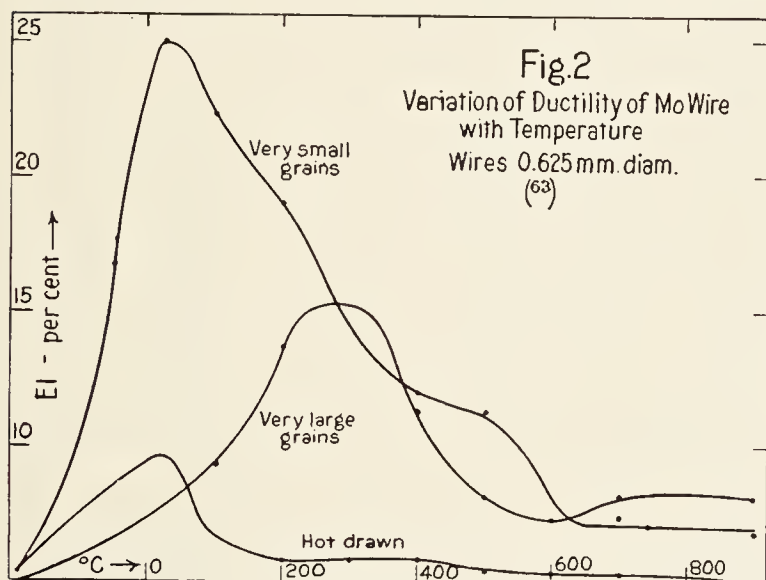
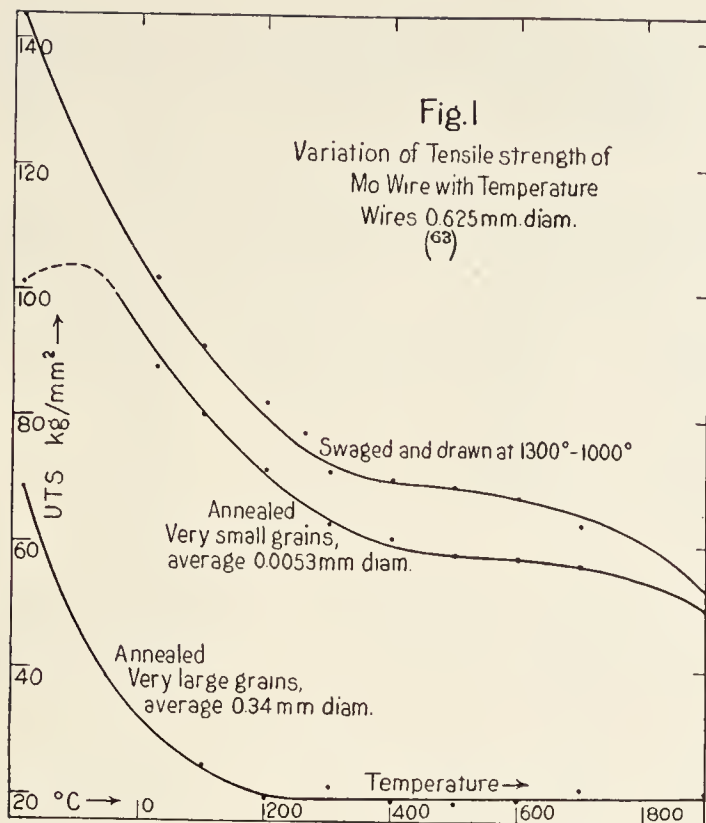


TABLE 3.—PROPERTIES OF Co-Cr AND STELLITE

Typical compositions of stellite

Co	Cr	W	Mo	Fe	Si	Mn	V	C	Remarks	Lit.
34.6	26.3	12.7	9.4	10.1	0.78	0.72	1.0	1.79	(1914)	(21)
55.6	33.6	9.1		Tr.	0.17	0	0	1.48	(1917)	(21)
54.9	32.9	9.1		1.0	0.29				Stellite 2	(54)
52.9	23.8	17.6		5.2	0.62				Stellite 3	(54)
59.5	10.8	0	22.5	3.1	0.77	2.04		0.87		(26)
38	30	16	4	(Ni, 10)				2-5	"Akrite"	(59)

Brinell hardness of stellite

$t, ^\circ\text{C} \dots \dots$	15	100	200	350	475	630	700	800	Lit.
BHN*.....	512	495	430	430	387	364	351	332	(21)

	As received	Quenched 1300°	Quenched 1000°	Lit.
Stellite 2.....	545	495	564	(26)
Stellite 3.....	590	594		

Co, 75; Cr, 25: UTS = 67 kg/mm<sup>2</sup>; EL = 56 kg/mm<sup>2</sup>; EL = 3% (14).

\* These data apparently for second alloy in above table.

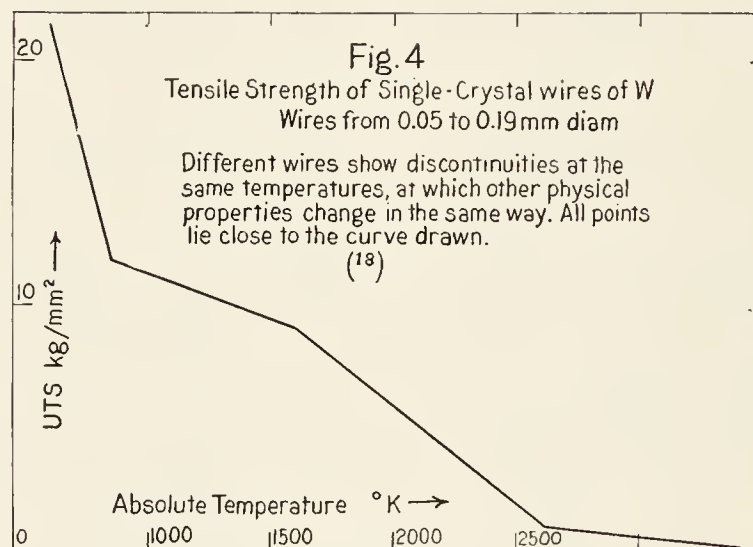


TABLE 4.—HARDNESS OF ALLOYS

% composition	$t, ^\circ\text{C}$	Hardness, Mohs' scale	Lit.
As, 57; Cd, 43.....	20	3.5-4	(73)
Mn, 80; Si, 20.....	15	6.5	(43)
Mn, 66; Si, 34.....	15	8.5	(43)
Mo, 88.9; C, 11.1.....	20	7-8	(51)
Si, 54; Ti, 46.....	22	4-5	(29)
Zr, 61.5; Si, 38.5.....	22	6	(29)

% composition	BHN	Lit.
Ce, 87; Cu, 13.....	61*	(23)
Ce, 54; Cu, 46.....	152*	(23)
Co, 90; W, 10.....	282†	(35)

\* 5 mm ball, 110 kg load.

† Maximum hardness for 25% Co.

TABLE 5.—EXTRUSION PRESSURE OF In-Pb AND K-Fb

In-Pb (aperture 2.81 mm diam.) (38)

% In.....	0	5.8	14.1	27.0	35.8	45.2	56.4	84.3	100
EP.....	10.6	14.7	18.2	21.0	23.7	21.0	18.2	11.5	3.1

K-Rb ( $t = 22^\circ\text{C}$ , aperture 2.85 mm diam) (37)

% Rb	0	9.4	12.8	26.7	31.2	55.7	67.2	85.6	90	96	100
10 EP	0.9	2.2	2.4	2.8	2.6	2.4	2.1	1.9	1.5	1.1	0.3

TABLE 6.—ELASTIC PROPERTIES OF TA AND W

Ta	$E = 1.9 \times 10^4 \text{ kg/mm}^2$ (4)
W	$E = 3.62 \times 10^4 \text{ kg/mm}^2$ at $20^\circ\text{C}$ } $dE/dt = \text{constant}$
	$= 3.31 \times 10^4 \text{ kg/mm}^2$ at $1000^\circ\text{C}$ } (10)
	Nearly same value $\nu$ . (16, 18, 72).
	$G = 1.51 \times 10^4 \text{ kg/mm}^2$ at $20^\circ\text{C}$
	$dG/dt$ is negative, amount varying with recrystallization of the wire (18, 31, 58, 72).
	$K = 2.82 \times 10^4 \text{ kg/mm}^2$ at $27^\circ\text{C}$ } (72)
	$= 3.62 \times 10^4 \text{ kg/mm}^2$ at $642^\circ\text{C}$ }
	$\lambda = 0.17$ (independent of temperature) (18).

TABLE 7.—SPECIFIC GRAVITIES OF ALLOYS

% composition	$t, ^\circ\text{C}$	$d_4^t$	Lit.
As, 55.5; Ca, 44.5.....	15	2.5	(41)
As, 62.8; Cd, 37.2.....	20	5.85	(73)
57 43.....	20	5.86	
55.7 44.3.....	20	5.92	
49.5 50.5.....	20	5.97	
As, 71.4; Co, 28.6.....	0	7.0	(11)
65.6 34.4.....	0	7.3	
56.0 44.0.....	0	7.6	
45.9 54.1.....	0	7.8	
As, 68.4; Cr, 31.6.....	22	6.2	(9)
59.0 41.0.....	16	6.3	
B, 62; Ca, 38.....	15	2.2	(53)
B, 57; Sr, 43.....	15	3.3	(53)
Ba, 73; As, 27.....	15	4.1	(41)
Ba, 67.7; B, 32.3.....	15	4.36	(53)
Ca, 55.3; Mg, 44.7.....	25	1.7	(2)
Co, 91.5; B, 8.5.....	20	7.9	(13)
Co, 89.27; Ni, 10.73.....		8.87	(3)
79.54 20.46.....		8.75	
69.77 30.23.....		8.77	
60.43 39.57.....		8.72	
Co, 79.2; P, 20.8.....		6.6	(74)
Co, 80.8; Si, 19.2.....		7.3	(42)
67.6 32.4.....		6.3	(66)
51 49.....		5.3	
Cr, 82.5; B, 17.5.....	15	6.1	(12)
87.7 12.3.....	15	6.7	
Cr, 91.4; C, 8.6.....	25	6.9	(56)
86.7; 13.3.....	21	6.68	
Cr, 50.8; W, 40.1; C, 9.1.....	22	8.4	(52)
Ga, 90; In, 10.....	20	5.95	(6)
K, 68.3; Na, 31.7.....	4.5	0.890	(22)
La, 85.3; C, 14.7.....	20	5.0	(46)
Mn, 97.0; C, 3.0.....		6.98	(62)
93.28 6.72.....		6.89	
Mn, 77.4; Mo, 22.6.....	0	7.3	(1)
69.5 30.5.....	0	7.8	
53.4 46.6.....	0	8.4	
36.4 63.6.....	0	8.6	
22.3 77.7.....	0	8.7	
Mn, 80; Si, 20.....	15	6.2	(43)
66 34.....	15	5.9	
49.3 50.7.....	13	6.2	
Mo, 94.1; C, 5.9.....		8.9	(47)
88.9 11.1.....	20	8.4	(51)

TABLE 7.—SPECIFIC GRAVITIES OF ALLOYS.—(Continued)

% composition	$t, ^\circ\text{C}$	$d_4^t$	Lit.
Mo, 77; Fe, 23.....	0	9.4	(67)
63 37.....	0	9.0	
53 47.....	0	9.2	
46 54.....	0	8.9	
Mo, 62.8; Si, 37.2.....	0	5.9	(30)
Na, 85.78; Hg, 14.22.....	17	1.125	(65)
79.9 20.1.....	110	1.17	
77.73 22.27.....	17	1.235	
71.0 29.0.....	110	1.28	
58.7 41.3.....	110	1.57	
56.35 43.65.....	17	1.716	
51.0 49.0.....	110	1.79	
Si, 96.5; Al, 3.5.....		2.4	(17)
85 15.....		2.4	
57 43.....		2.5	
Si, 58.7; Ca, 41.3.....		2.5	(49)
Si, 89.1; Cr, 10.9.....		2.6	(17)
75.8 24.2.....		2.9	
70 30.....		3.1	
65.3 34.7.....		3.3	
62 38.....		3.5	
57.8 42.2.....		4.0	
52.4 47.6.....		4.7	
51 49.....		4.8	
Si, 90.5; Cu, 9.5.....		2.5	(17)
69.6 30.4.....		3.0	
68 32.....		3.1	
51.6 48.4.....		3.6	
50.4 49.6.....		3.9	
Si, 95.0; Fe, 5.0.....	18	2.4	(25, 60)
79.4 20.6.....	18	2.75	
61.5 38.5.....	18	3.9	
51.8 48.2.....	18	4.4	
50.1 49.9.....	18	4.7	
Si, 71.8; Li, 28.2.....		1.1	(48)
Si, 66.8; Ni, 33.2.....		3.5	(17)
57.3 42.7.....		3.9	
52.6 47.4.....		4.2	
Si, 54; Ti, 46.....	22	4.0	(29)
Sr, 54; As, 46.....	15	3.6	(41)
Ta, 80.4; Si, 19.6.....	0	8.8	(30)
Th, 90.6; C, 9.4.....	18	9.0	(50)
Th, 80.5; Si, 19.5.....	16	7.95	(28)
V, 81; C, 19.....		5.4	(46)
W, 93.88; C, 6.12.....	18.5	15.6	(57, 69)
W, 73.6; Fe, 22.4; C, 4.0.....	18	13.4	(70)
W, 76.5; Si, 23.5.....	0	9.4	(7)
Zr, 61.5; Si, 38.5.....	22	4.9	(29)

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## FATIGUE OF METALS AND ALLOYS

H. J. GOUGH

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Torsional stress, various mean stresses.	Effort de torsion, efforts moyens variés.	Drehspannungen mit verschiedenem Mittelwert.	Sforzo di torsione, valori vari medi delle sollecitazioni . . . . .	607
Direct stress at various temperatures.	Effort direct à des températures variées.	(Zug-bezw. Druck)-Wechselspannungen bei verschiedener Temperatur.	Sforzi assiali a varie temperature . . . . .	608
Reversed bending stress at various temperatures.	Effort de flexion plane à des températures variées.	Ebenengleiche Biegespannungen bei verschiedener Temperatur.	Sollecitazioni per piegamento a varie temperature . . . . .	608

The data on fatigue of metals and alloys are arranged according to the following scheme:

1. The chemical symbols of the principal constituents of each non-ferrous alloy are arranged in order of descending magnitude of their proportions in the alloy. Thus section 3 (Al-Cu-Mg-Si) contains alloys whose largest constituent is Al; the next largest Cu and the third largest is Mg, any other elements present having minor effect on the properties (*v. also* Introduction, p. 358). The sections are numbered consecutively.

2. The steels are arranged in the same manner except that C is written last in the type formula.

3. The different sections, each containing alloys of the same type formula are arranged in alphabetical order.

4. The alloys within each section are arranged in descending magnitude of proportion of largest constituent if this is given by analysis, if not, in order of ascending magnitude of proportion of second constituent; they are numbered consecutively in each section.

5. In the figures, the composition number of any alloy is the combination of its section number and number within the section. Thus the Al-Cu alloy containing 12% Cu has the composition number 2:4.

6. In Tables 2-9, the alloys follow the same arrangement as in Table 1, which should be consulted for exact composition.

TABLE 1.—COMPOSITION OF ALLOYS

Comp. No.	% composition, Al +							Table
	Cu	Fe	Mg	Mn	Ni	Si	Zn	
1. Al								
1	0.12	0.49				0.15		3
2	(99.6% Al) Single crystals*							2, 5
2. Al-Cu								
1	2.0			1.0				3
2	4.55	0.56		0.82		0.82		3
3	8.0							3
4	12.0	0.69				0.38	0.05	3
5	12.6	0.82				0.37	Tr.	3
3. Al-Cu-Mg-Si								
1	3.25	0.28	0.70	Tr.		0.28	Dur- alumin	3
2	3.61	.74	.70	0.60		.48		3
3	3.75	.60	.26	.69		.40		3
4	3.88	.45	.78	.64		.26		3
5	4.0		.50	1.0		1.0		3, 9
6	4.18		.66			0.19		3
7	4.28	.54	.42	0.62		.34		3
8	5.0		.75	.5		.75		3, 9
9	6.0		.75	.5		1.0		3, 9

TABLE 1.—COMPOSITION OF ALLOYS.—(Continued)

Comp. No.	% composition, Al+							Table
	Cu	Fe	Mg	Mn	Ni	Si	Zn	
4. Al-Cu-Ni-Mg								
1	2.0		1.0		1.5	0.6	“Magnalite”	3, 9
2	4.0		1.0		1.0			3
3	4.0		1.50		1.0			3
4	4.0		1.50	0.50	2.0	0.75	Ind. No. 1491	3, 9
5	4.0	0.20	1.50	0.50	2.0	.20	Modified “Y” alloy	3, 9
6	4.0	.20	1.50		2.0	.20	“Y”	3, 9
7	4.0		1.5		2.0		alloy	3
5. Al-Cu-Zn								
1	8.7	0.57				0.33	5.3	3
2	9.5	.75				.35	5.5	3
6. Al-Mg								
1		0.8	6.2	“Aeromin”		0.30		3, 9
7. Al-Mg-Si								
1	0.15	0.54	0.55	0.006		0.56		3
8. Al-Si								
1						5.0		3
2						8.0		3
3		0.30				8.5		3
4		0.45				11.04		3
5						12.65		3
6		0.5	(Ca,0.05;Na,0.006)			12.7		2, 8
7						13.0		3
8		0.35				13.75		3
9. Al-Zn								
1							5.21	2
2							9.26	2
3							11.0	2
4							16.85	2
5							26.0	2
10. Al-Zn-Cu								
1	3.04	1.23			Sn	0.29	7.73	3
2	2.07	0.62			0.05	0.27	11.4	3
3	2.17	0.73			0.06	0.30	12.1	3
4	3.0						15.9	3
5	2.5	0.20	0.5	0.5	“E” alloy	1.0	20.0	3, 9
6	2.9	0.20	“A” alloy			0.25	20.3	3, 9
7	3.0	0.20	“B” alloy			0.25	25.0	3
Comp. No.	% composition							Table
	Cu	Al	Fe	Ni	Pb	Sn	Zn	
11. Cu, Electrolytic or Commercially Pure								
1	99.993		0.0052		<0.002			5
2	99.992		.0058		<0.002			5
3	99.991†		.008		<0.001			3
4	99.98		.02					3
5	99.96		Tr.	Tr.	Tr.			3
6	99.895							3
Comp. No.	% composition						Table	
	Cu	O	Fe	Ni	S			
12. Cu, Oxygenated								
1	99.954	0.036	0.002	0.0015	0.0002	These also	3	
2	99.94	.049	.002	.0015	.0002	contain	3	
3	99.90	.094	.002	.0015	.0001	0.001 Ag,	3	
4	99.75	.240	.002	.0015	.0005	0.0015 As, 0.002 Sb	3	

TABLE 1.—COMPOSITION OF ALLOYS.—(Continued)

Comp.	% composition							Table
No.	Cu	Al	Fe	Mn	Ni	Si	Zn	
13. Cu-Al, Al-Bronzes								
1	99.86	0.10						2
2	96.98	2.99	0.008			0.024		2
3	94.90	5.07	.006			.018		2
4	94.85	5.62	.065					3, 5
5	92.61	9.90	.017			.027		2
6	90.91	9.10	.002					3, 5
7	90.52	10.01	.002					3, 5
8	90.22	9.78						3
9	90.06	7.35	.017			.027		2
10	89.81	10.06						3
11	89.0	10.0	1.0					3
12	87.12	10.4	2.92					3, 5
14. Cu-Al-Mn								
1	89.06	10.2	0.01	0.92		0.01		2
2	88.30	9.82	.03	1.88		.34		2
3	88.11	8.91	.02	2.98		.02		2
15. Cu-Al-Ni								
1	87.45	7.91			4.64			2
2	87.45	6.93			5.62			2
3	87.32	5.34			7.34			2
16. Cu-Mn								
1	96.2		0.18	3.58				2
Comp.	% composition							Table
No.	Cu	Fe	Mn	Ni	C	Sn	Zn	
17. Cu-Ni								
1	80.34	0.27	0.12	19.23	0.03			3
2	80.03	.16		19.43				3
3	78.92	.19	0.26	20.61		Cupro-nickel		3
4	53.77	.52	1.14	44.68	.11	Constantan		3, 5
5	53.71	.66	0.89	44.77	.078			3
18. Cu-Ni-Cr								
1	58.93	1.04	1.61	34.15	+(Cr, 4.14; Si, 0.13)			3, 5
19. Cu-Ni-Sn								
1	69.82	0.27		29.08	0.07	0.95		3
20. Cu-Ni-Zn								
1	74.01	0.34	0.75	19.75	0.07		5.17	3, 5
2	60.08	.20		10.89	German silver		29.05	3
Comp.	% composition							Table
No.	Cu	Fe	Mn	P	Pb	Sn	Zn	
21. Cu-Sn, Bronzes								
1	96.12			0.32		3.54	Phos. bronze	2
2	95.74			.048		4.20		3
3	95.61	0.031		.056	0.002	4.66		5
4	95.57	.09		.39	<0.01	4.05	Phos. bronze	3
5	94.96					4.89		3
6	95.0			.026	0.01	5.06		3
7	89.39	.08		.13	<0.01	10.6	Phos. bronze	3
22. Cu-Zn, Brasses								
1	81.0	0.05			<0.01		19.06	3
2	73.28	.135			.026		26.61	3
3	72.36	.13	(S = 0.035 %)		.13		27.46	2
4	71.69	.13			.017		28.24	5
5	70.08	.05			<0.01		29.99	3



TABLE 1.—COMPOSITION OF ALLOYS.—(Continued)

Comp. No.	% composition							Table	
	Cu	Fe	Mn	P	Pb	Sn	Zn		
22. Cu-Zn, Brasses.—(Continued)									
6	69.85	0.04				Tr.	30.11	3	
7	66.3	(Naval brass, $\alpha$ )			0.25	1.20	32.2	2	
8	65.0						34.6	3	
9	61.20	(Naval brass)			0.10	0.43	38.27	3	
10	60.81	.002	(Naval brass)		.002	0.85	38.32	3	
11	60.25	.02			.02		39.61	3	
12	59.78	.03			.08		40.11	3	
13	59.65	.164	(Muntz metal)		.20	0.10	40.11	3, 5	
14	58.5	.87	(Naval brass, $\alpha, \beta$ )			0.50	40.1	2, 6	
15	58.19	.65	(Mn bronze)		0.02	1.04	40.10	3	
16	58.0	.80	(Muntz metal)			Tr.	41.2	2	
17	56.85	1.50	(Mn bronze)			0.32	40.90	3	
22.5. Cu-Zn-Pb, Leaded Brasses									
1	61.60	0.03			0.06		38.31	3	
2	61.54	.04			0.53		37.89	3	
3	61.03	.03			1.58		37.89	3	
4	59.58	.03			2.61		37.78	3	
5	59.40	.03			3.43		37.14	3	
Comp. No.	% composition, Fe+							Table	
	C				Mn	P	S		Si
23. Fe, Commercially Pure									
1	0.012	Armco iron			0.07	0.014	0.017	0.017	2, 3, 5
2	.02	Ingot iron			.03	.005	.042	.02	2, 3, 4, 5
3	.023				.037	.002	.031	.005	3
4	.029	Wrought iron			.07	.219	.024	.127	2
5	.039				Tr.	.018		Tr.	2
6	.045				0.024	.246	.017	0.234	2, 3
7	.06				.12	.25	.023	.13	3
8	.195				.005	.054	.011	.086	2
Comp. No.	% composition, Fe+							Table	
	C	Cr	Mn	Ni	P	S	Si		
24. Fe-C, Carbon Steels									
1	0.065	(Comp. Nos. 2, 11, and 14 are case-hardening steels)	0.04	0.12	0.135	0.010	0.148	2	
2	.11		.73		.02	.018	.10	3	
3	.13		.70		.046	.042	.18	2, 3, 5	
4	.13		.30		.028	.017	.028	2, 6	
5	.14		.68		.045	.04	.19	3	
6	.14		.53		.008	.056	.17	3	
7	.15							2, 3	
8	.15		.30		.018	.034	.06	3	
9	.16							2	
10	.17		.10		.013	.012	.021	2	
11	.17		.46		.023	.032	.12	3	
12	.18		.37		.013	.039	.06	3	
13	.19		.60		.052	.047	.024	2	
14	.19		.65		.025	.049	.05	3	
15	.20	.67	.025	.090	.03	3			
16	.20	0.06	.58	0.18	.044	.034	.18	3	
17	.21	.017	.82	.206	.06	.08	.08	3	
18	.24		.83		.033	.043	.33	2, 6	
19	.24		.45		.009	.051	.007	3, 5	
20	.25		.65		.05	.03	.06	2, 3, 5	
21	.25		1.18		.031	.04	.25	3, 5	
22	.26		0.54		.027	.031	.05	3	
23	.27		.58		.055	.038	.065	2, 6	

TABLE 1.—COMPOSITION OF ALLOYS.—(Continued)

Comp. No.	% composition, Fe+							Table		
	C	Cr	Mn	Ni	P	S	Si			
24. Fe-C, Carbon Steels.—(Continued)										
24	0.29	<div>Comp. Nos. 55 and 68 are spring steels</div>	0.52	<div>0.12</div>	0.01	0.051	0.17	3		
25	.29		.75		.057	.046	.037	2, 6		
26	.30		.05		.04	3				
27	.31		.47		.013	.03	.16	3		
28	.31		.67		.04	.048	.14	3		
29	.31		.86		.078	.091	3			
30	.32		.58		.049	.052	.22	3		
31	.33		.59		.049	.051	.22	2, 3, 5		
32	.34		.68		.045	.023	.055	2, 6		
33	.34		.56		.026	.021	.072	2		
34	.35		2							
35	.36		.66		.02	.041	.25	3		
36	.37		2, 3							
37	.37		.58		.032	.035	.16	2, 3, 4, 5		
38	.38		.69		.025	.030	.066	2, 6		
39	.38		.57		.033	.048	.04	3, 5		
40	.40		.77		.029	4				
41	.40		.05		.08	3				
42	.41		.54		.017	.024	.14	5		
43	.42		.62		.02	.03	.17	3		
44	.44		1.05		.30	4				
45	.446		0.47		.067	.044	.063	2		
46	.45		2							
47	.45		.54		0.12	.017	.016	.15	3	
48	.46		.68		.13	.015	.021	.11	5, 7	
49	.48		.60		.010	.038	.19	3		
50	.49		.46		.017	.029	.12	2-5, 7, 9		
51	.51		.59		.053	.038	.083	2, 6		
52	.52		.56		.037	.029	.24	3, 4, 5		
53	.53		.48		.017	.037	.12	2, 3		
54	.57		.60		.058	.034	.121	2, 6		
55	.60		0.09		.77	.03	.011	.007	.21	3
56	.60		{ Comp. Nos. 55 and 68 are spring steels }		.69	.039	.04	.20	3	
57	.62				.23	.011	.031	.186	2, 6	
58	.63				.56	.055	.038	.111	2, 6	
59	.645				.26	.028	.010	.062	2	
60	.65				.11	.03	.020	.14	2, 3, 5, 8	
61	.71				.72	.11	.029	.032	.44	3
62	.72				.26	.015	.032	.163	2, 6	
63	.77				{ Comp. Nos. 55 and 68 are spring steels }	.55	.037	.047	.18	3
64	.79					.30	.015	.032	.182	2, 6
65	.81					.32	.012	.031	.16	3, 5
66	.93					.38	.017	.045	.03	2, 3, 4, 5
67	.97					.31	.18	.019	.020	.13
68	1.02		.24			.012	.029	.145	3, 9	
69	1.20		.25		.021	.021	.19	2-5, 7		
Comp. No.	% composition, Fe+						Table			
	C, graph- ite		C, com- bined		Mn	P		S	Si	
25. Fe-C, Cast Iron										
1	1.70		0.56		0.95	0.045	0.037	2.49	2, 8	
2	1.97		.46		.27	1.48	.069	2.07	2	
3	2.10		.47		.77	0.060	.029	2.30	2	
Comp. No.	% composition, Fe+							Table		
	Ce		C		Mn	Ni	P		S	Si
26. Fe-Ce-C, Ce-Steels										
1	{ 0.41 — 0.61 }		0.38		0.68				0.35	4

TABLE 1.—COMPOSITION OF ALLOYS.—(Continued)

Comp. No.	% composition, Fe +							Table
	Cr	C	Mn	Ni	P	S	Si	
<b>27. Fe-Cr-C, Cr-Steels</b>								
Stainless steels, excepting No. 1								
1	0.94	0.35	0.62				0.35	4
2	11.71	.085	.32	0.13	0.019	0.042	.594	2
3	11.78	.08	.07	Cu, 0.05	.017	.007	.11	3
4	12.33	.247	.36		.012	.075	.09	2, 3
5†	12.26	.42	.27	0.20	.016	.058	.056	3, 5
6	12.9	.32	.30	.3	.026	.03	1.36	3
7	13.18	.09	.03	(Stainless iron)			0.06	3, 5
8	13.34	.08	.06	0.12	0.017	.003	.08	3
9	13.31	.21	.59	.13	.017	.017	.79	3
10	14.31	.104	.447	Tr.	.006	Tr.	.935	2
11†	14.99	.85	.39	.26	.020	.005	.16	3, 5
12	15.21	.40	.28	.18	.017	.058	.59	3, 5
13†	15.81	.61	.39	.24	.018	.035	.03	3, 5
Comp. No.	% composition, Fe +							Table
	Cr	Ce	C	Mn	Ni	Si		
<b>28. Fe-Cr-Ce-C, Cr-Ce-Steels</b>								
1	0.98	0.41-0.50	0.41	0.64		0.27		4
Comp. No.	% composition, Fe +							Table
	Cr	Mo	C	Mn	P	S	Si	
<b>29. Fe-Cr-Mo-C, Cr-Mo-Steels</b>								
1	0.55	0.39	0.42	0.55			0.19	4
2	.73	.28	.15	.36			.12	4
3	.76	.18	.39	.49	0.034	0.035	.195	3
4	.79	.34	.22	.59			.14	4
5	.85	.20	.31	.44	.034	.035	.22	3
6	.88	.30	.40	.65			.12	4
7	.89	.36	.41	.63			.28	4
8	.95	.10	.40	.52	.033	.024	.26	3
9	.95	.39	.52	.71			.16	4
10	.95	.68	.40	.62			.40	4
11	.95	.73	.25	.48			.19	4
12	1.03	.19	.50	.48	.030	.039	.24	3
13	1.04	.09	.42	.53	.032	.023	.25	3
Comp. No.	% composition, Fe +							Table
	Cr	V	C	Mn	P	S	Si	
<b>30. Fe-Cr-V-C, Cr-V-Steels</b>								
1	0.93	0.16	0.41	0.67	C. No.	Ni	0.13	4
2	.93	.20	.40	.64	5	0.20	.31	4
3	.95	.20	.44	.49	6	.173		3
4	.99	.19	.55		8	.19		3
5	1.00	.16	.45	.56	0.016	0.030	.13	3, 5
6	1.16	.23	.24	.30	.046	.044	.29	3
7	1.46	.23	.53	.50	.005	.038	.22	3
8	1.48	.33	.46	.64	.31	.28	.19	3
9	13.47	.27	.03		.04	.01		3
Comp. No.	% composition, Fe +							Table
	Mo	C		Mn	P	S	Si	
<b>31. Fe-Mo-C, Mo-Steels</b>								
1	0.34	0.44		1.29			0.33	4
2	.37	.38		0.71			.35	4
3	.67	.41		0.72			.42	4
4	.73	.43		1.24			.46	4
5	1.05	.46		0.75			.43	4
6	3.00	.36		0.65			.30	4

TABLE 1.—COMPOSITION OF ALLOYS.—(Continued)

Comp.	% composition, Fe +							Table
No.	Ni	C	Cr	Mn	P	S	Si	
32. Fe-Ni-C, Ni-Steels								
1	2.93	0.38	0.23	0.62	0.032	0.03	0.19	2, 3
2	2.96	.39		.55	.031	.039	0.11	3
3	3.00	.41		.70			2.47	4
4	3.06	.39		.61	.024	.019	0.14	3, 5
5	3.12	.12		.30	.022	.022	.037	2, 6
6	3.25	.38		.28	.027	.024	.063	2, 6
7	3.35	.31		.64	.026	.028	.13	3, 5, 7
8	3.41	.41	0.18	.75	.02	.02	.25	2-7
9	3.56	.14	Comp. Nos. 14-16 are case hardening steels.	.50	.029	.021	.19	2, 6
10	3.60	.42		.70	.017	.016	.12	3, 5
11	3.70	.29		.66	.005	.046	.14	3
12	3.74	.28		.578	.014	.047	.195	5, 7
13	4.70	.50		.32	.023	.027	.233	2, 6
14	4.84	.14		.29	.009	.018	.16	3
15	5.10	.13		.16	.038	.038	.187	3
16	5.76	.11		0.10	.20	.033	.031	.18
Comp. Nos. 14-16 are case hardening steels.								
Comp.	% composition, Fe +							Table
No.	Ni	Ce	C	Mn	S	Si		
33. Fe-Ni-Ce-C, Ni-Ce-Steels								
1	2.86	0.33 to 0.58	0.43	0.91		2.54		4
Comp.	% composition, Fe +							Table
No.	Ni	Cr	C	Mn	P	S	Si	
34. Fe-Ni-Cr-C, Ni-Cr-Steels								
1	0.47	1.10	0.43	0.63	0.012	0.038	0.22	3
2	1.23	0.65	.47	.64			.36	4
3	1.36	.65	.368	.681	.012	.013	.13	5, 7
4	1.41	.81	.46	.82	.015	.020		3
5	1.45	1.10	.41	.64	.009	.033	.20	3
6	1.75	0.99	.49		Nos. 10, 11			3
7	2.49	.83	.37	.63	are case hard-		.28	4
8	2.56	.83	.36	.65	ening steels		.33	4
9	2.93	.69						2
10	3.00	.48	.19	.45	0.021	0.028	.32	3
11	3.15	.58	.20	.39	.022	.033	.28	3
12	3.18	.96	.33	.47	.007	.052	.18	3
13	3.33	.84						2
14	3.33	.87	.24	.37	.019	.025	.15	3, 4, 5, 7
15	3.33	.18	.41	.65	.018	.025	.15	3, 9
16	3.45	.76	.32	.60	.03	.03	.12	3
17	3.48	.78	.32	.46			.23	3
18	3.6	.6	.30	.40	.02	.02	.17	2, 6
19¶	4.30	1.40	.30	.56	.015	.041	.22	3
20	4.65	0.29	.16	.43	.033	.044	.11	3
21	19.70	8.31	.33	.49	{ Stainless steel "Cyclops metal"		1.16	3, 5, 9
Comp.	% composition, Fe +							Table
No.	Ni	Cr	C	Cu	Mn	P	S	Si
35. Fe-Ni-Cr-Cu-C, Ni-Cr-Cu-Steels (Stainless Steels)								
1	12.1	0.01	0.80	0.05	0.86	0.017	0.045	1.70
2	15.88	0.05	.38	.08	.71	.020	.048	2.36
3	22.90	5.42	.24	.78	.80	.010	.027	1.65
4	25.27	17.71	.39	.12	.66	.018	.030	1.44
5	25.81	17.32	.70	.05	.72	.018	.060	3.08
6	28.20	8.38	.45	.67	.49	.012	.022	1.39



TABLE 1.—COMPOSITION OF ALLOYS.—(Continued)

Comp. No.	% composition, Fe+								Table
	Ni	Cr	Ce	C	Mn	P	S	Si	
<b>36. Fe-Ni-Cr-Ce-C, Ni-Cr-Ce-Steels</b>									
1	1.02	0.84	0.12	0.54	0.84			0.48	4
2	1.17	.77	.25	.41	.63			.33	4
3	2.46	.92	.19	.36	.66			.34	4
4	2.47	.95	.24	.43	.58			.35	4
Comp. No.	% composition, Fe+								Table
	Ni	Cr	Mo	C	Mn	P	S	Si	
<b>37. Fe-Ni-Cr-Mo-C, Ni-Cr-Mo-Steels</b>									
1	1.27	0.67	0.83	0.41	0.64			0.41	4
2	1.28	.68	.31	.39	.66			.27	4
3	2.39	.86	.75	.50	.63			.44	4
4	2.44	.82	.37	.44	.66			.43	4
5	2.45	.88	.35	.46	.61			.32	4
6	2.49	.79	.76	.41	.60			.31	4
7	2.52	.83	.34	.53	.65			.36	4
8	2.53	.78	.75	.38	.61			.48	4
9	4.83	.96	.89	.27	.35	0.015	0.02	.13	3
Comp. No.	% composition, Fe+								Table
	Ni	Cr	V	C	Mn	P	S	Si	
<b>38. Fe-Ni-Cr-V-C, Ni-Cr-V-Steels</b>									
1	1.20	0.75	0.24	0.39	0.71			0.28	4
2	2.52	.84	.20	.40	.61			.28	4
3	3.30	.60	.10	.30		0.034	0.022	.31	2, 3
Comp. No.	% composition, Fe+								Table
	Ni	Mo		C	Mn	P	S	Si	
<b>39. Fe-Ni-Mo-C, Ni-Mo-Steels</b>									
1	1.70	0.12		0.41	0.46	0.037	0.020	0.22	3
2	2.95	.70		.37	.52			2.50	4
Comp. No.	% composition, Fe+								Table
	Ni	V		C	Mn	P	S	Si	
<b>40. Fe-Ni-V-C, Ni-V-Steels</b>									
1	2.94	0.12		0.36	0.51			2.42	4
Comp. No.	% composition, Fe+								Table
	Ni	Zr		C	Mn	P	S	Si	
<b>41. Fe-Ni-Zr-C, Ni-Zr-Steels</b>									
1	3.00	0.24		0.43	0.57			2.40	4
Comp. No.	% composition, Fe+								Table
	Si	Mn	C			P	S		
<b>42. Fe-Si-Mn-C, Si-Mn-Steels</b>									
1	1.97	0.65	0.55	(Spring steel)		0.024	0.037		3
Comp. No.	% composition								Table
	Mg	Al	Cu	Zn	Fe	Mn	Si		
<b>44. Mg, Commercial</b>									
1	99.96				0.02		0.02		3
2	99.89	Tr.	0.02		0.03		0.06		3

TABLE 1.—COMPOSITION OF ALLOYS.—(Continued)

Comp. No.	% composition								Table
	Mg	Al	Cu	Zn	Fe	Mn	Si		
<b>45. Mg-Al</b>									
1	95.77	4.20			0.03				3
2	95.31	4.40			.03	0.26			3
3	94.0	6.0							3
4	93.26	6.70			.04				3
5	92.90	6.80			.04	0.26			3
6	91.23	8.68	0.026		.041		0.023		3
<b>46. Mg-Cu</b>									
1	90.31		9.65		0.04				3
<b>47. Mg-Zn</b>									
1§	94.72	Tr.	0.41	4.38	0.25		0.24		3
Comp. No.	% composition								Table
	Ni	Cu	Fe	Mn	C	S	Si		
<b>48. Ni, Commercial</b>									
1	99.32		0.32		0.15	0.016	0.023		2, 3
2	99.07	0.159	.59	0.184	.044	.025	.008		3, 5
3	99+								3
4	98.95	.12	.50	.10	.25	.175	.06		3, 5
5	98.70	.23	.74	.16	.099	.16	.06		3
<b>49. Ni-Cr</b>									
1	79.7	0.13	0.88		0.09	0.012	0.10		2, 8
+Cr, 19.04; Mg, 0.05									
<b>50. Ni-Cu</b>									
1	76.66	21.28	1.40	0.26	0.26	0.006	0.065		3
2	72.91	23.56	1.73	1.94	.216	.007	.075		3
3	69.08	28.07	1.56	1.01	.18	.005	.02		3
4	68.95	27.29	2.22	1.38	.20	.019	.03		3, 5
5	67.74	28.64	1.75	1.62	.21	.019	.01		3
6	66.81	29.65	1.53	1.79	.18	.015	.02		3
7	66.78	29.54	2.10	1.44	.16	.039	.02		3, 5
8	66.0	30.0	2.10	1.30	.19	.03			3
9	65.28	30.53	2.12	1.53		.027	.14		2
10	55.23	44.18	0.44	0.36	.016	.009	.002		3

4 has trace Al; 1 has 0.023 P; 4 has 0.19 P; 5 has 0.014 P; 7 has 0.019 P; 8 has 0.04 P; 10 has 0.006 P. 1-7 are Monel metals.

**51. Ni-Cu-Mn**

1	68.74	28.16	0.56	2.35	0.10	0.008	Tr.		2, 8
2	67.51	26.23	1.39	4.31	0.20	0.028	0.40		3

\* The mechanical properties depend to some extent on the relative positions of the specimen and crystallographic axes.

† By difference.

‡ 5 has 0.04 Cu, 11 has 0.03 Cu, 13 has 1.10 Cu.

¶ Air hardening steel.

§ Electron metal.

|| Contains 0.024 P.

TABLE 2.—ENDURANCE LIMITS UNDER REVERSED DIRECT STRESSES

Key No.*	Treatment	Approximate composition	Millions of reversals, $10^{-6}n$ †	Endurance limit, kg/mm <sup>2</sup> $F/L_0$ [Def. 17(b)]	Endurance limit Tensile strength	Lit.
<b>1. Al</b>						
2	A, single crystal§	Al, 99.6	6 H†	2.52§	0.38	(9.5)
<b>8. Al-Si</b>						
6A	G <sub>m</sub> M.....	Si, 12.7	10 H†	6.0	0.27	(22)
B	G <sub>m</sub> M, 250°/180 C <sub>a</sub> .....		10 H†	4.7	0.24	(22)
C	G <sub>s</sub> M.....		10 H†	7.1	0.36	(22)

TABLE 2.—ENDURANCE LIMITS UNDER REVERSED DIRECT STRESSES.—(Continued)

Key No.*	Treatment	Approximate composition	10 <sup>-6</sup> n	FL <sub>0</sub>	FL <sub>0</sub> /UTS	Lit.
<b>9. Al-Zn</b>						
1	R <sub>h</sub> .....	Zn, 5	1	3.9	0.28	(23)
2	R <sub>h</sub> .....	9	1	5.3	.32	(23)
3	R <sub>h</sub> .....	11	1	6.8	.37	(23)
4	R <sub>h</sub> .....	17	1	7.9	.28	(23)
5	R <sub>h</sub> .....	26	1	9.4	.24	(23)
<b>13. Cu-Al, Al-Bronzes</b>						
1	R <sub>h</sub> .....	Al, 0.1	1	7.3	0.32	(4)
2	R <sub>h</sub> .....	3.0	1	13.4	.43	(4)
3	R <sub>h</sub> .....	5.1	1	16.2	.39	(4)
5	R <sub>h</sub> .....	9.9	1	16.2	.35	(4)
9	R <sub>h</sub> .....	10.0	1	22.3	.37	(4)
<b>14. Cu-Al-Mn</b>						
1	R <sub>h</sub> .....	Al, 10; Mn, 1	1	19.5	0.29	(24)
2	R <sub>h</sub> .....	Al, 10; Mn, 2	1	19.5	.30	(24)
3	R <sub>h</sub> .....	Al, 9; Mn, 3	1	19.5	.31	(24)
<b>15. Cu-Al-Ni</b>						
1A	900° Q <sub>w</sub> .....	Al, 7.9; Ni, 4.6	H†	17.7		(2)
B	900° Q <sub>w</sub> 700°/30 C <sub>a</sub> .....		H†	19.7		
2A	900° Q <sub>w</sub> .....	Al, 6.9; Ni, 5.6	H†	16.9		(2)
B	900° C <sub>s</sub> (900-700° in 200 m)		H†	20.4		
3	900° Q <sub>w</sub> 700°/30 C <sub>a</sub> .....	Ni, 7.3; Al, 5.3	H†	23.2		(2)
<b>16. Cu-Mn</b>						
1	A.....	Mn, 3.6	10 H†	11.8	0.42	(27)
<b>21. Cu-Sn, Bronzes</b>						
1	As received, R (P-bronze)...	Sn, 3.5; P, 0.032	10 H†	15.2	0.47	(27)
<b>22. Cu-Zn, Brasses</b>						
3	As received, R.....	Zn, 27.5	10 H†	13.2	0.35	(27)
7	As received, R (naval brass, α).....	32.2	2 H†	13.8	.38	(12)
14A	As received (naval brass, αβ).....	Zn, 40.1	2 H†	18.9	.42	(12)
B	A.....		2 H†	18.5	.45	(12)
16A	As received (Muntz metal).....	Zn, 41.2	2 H†	19.7	.38	(12)
B	A.....		2 H†	17.3	.42	(12)
<b>23. Fe, Commercially Pure</b>						
1A	A 1000°/30 C <sub>f</sub> .....	Fe, 99.87; C, 0.012 {	10 H†	15.6	0.53	(9)
B	N 950°.....		10 H†	18.7	.54	(27)
2A	As received, A <sub>B</sub> (ingot iron).....	Fe, 99.88; C, 0.02	10	11.9	.40	(20)
4	As received.....	C, 0.03	2	17.0	.45	(26)
5	A.....	.04	H†	15.2	.50	(12)
6	F.....	.05	10	11.2	.34	(20)
8	As received.....	.195	2	15.1	.37	(26)
<b>24. Fe-C, Carbon Steels</b>						
1	As received.....	C, 0.07	2	14.9	0.43	(26)
3	N 850°.....	C, 0.13	10 H†	21.7	.45	(9)
4	R <sub>h</sub> .....	.13	8 H†	20.5	.51	(12)
7	A.....	.15	H†	17.2	.50	(29)
9	As received, R.....	.16	10 H†	19.7	.44	(27)
10	As received, R.....	.17	2	21.1	.46	(26)
13A	As received, R <sub>h</sub> .....	C, 0.19	1	18.5	.41	(25)
B	R <sub>h</sub> A 900°.....	.19	1	17.1	.40	
18A	As received.....	C, 0.24	1	22.7	.38	(25)
B	A.....	.24	1	20.7	.36	
20	As received, R.....	C, 0.25	8 H†	19.4	.42	(9)
23	As received, R.....	.27	1	21.2	.41	(25)
25	As received, R.....	.29	1	21.6	.40	(25)
31	850°/15 C <sub>a</sub> .....	.33	10 H†	22.1	.27	(11)
32	As received.....	C, 0.34	1	22.8	.39	(25)
33	F.....	.34	2	16.2	.35	(26)
34	As received.....	.35	3 H†	27.5	.41	(12)
36	A.....	.37	H†	23.2	.41	(29)
37A	As received.....	C, 0.37	10	17.6	.34	(20)
B	810°/15 C <sub>fo</sub> .....	.37	10	14.8	.29	
C	845°/15 Q <sub>w</sub> , 570° C <sub>a</sub> (sor-bitic).....	.37	10	23.2	.32	

TABLE 2.—ENDURANCE LIMITS UNDER REVERSED DIRECT STRESSES.—(Continued)

Key No.*	Treatment	Approximate composition	10 <sup>-6</sup> n	FL <sub>0</sub>	FL <sub>0</sub> /UTS	Lit.	
24. Fe-C, Carbon Steels.—(Continued)							
38	As received, R.....	C, 0.38	1	23.3	0.38	(25)	
45	As received.....	.44	2	22.4	.32	(26)	
46	As received.....	.45	10 H†	23.3	.35	(27)	
50B	925°/20 C <sub>a</sub> .....	C, 0.49	10	14.1	.22	(20)	
51	As received.....	.51		20.3	.29	(25)	
53A	925°/20 C <sub>a</sub> .....	.53	10	16.9		(20)	
54	As received.....	C, 0.57	1	26.8	.36	(25)	
57	As received.....	.62	1	22.4	.31	(25)	
58	As received.....	.63	1	28.0	.39	(25)	
59	As received.....	C, 0.64	2	24.9	.33	(26)	
60	N 800°.....	.65	10 H†	30.2	.38	(9)	
62	As received.....	.72	1	21.2	.24	(25)	
64	As received.....	.79	1	23.6	.38	(25)	
66	As received.....	.93	10	24.6	.26	(20)	
69	795°/15 C <sub>f</sub> , 860°/15 C <sub>to</sub> ...	1.20	10	19.3	.24	(20)	
25. Fe-C, Cast Irons							
1	As cast.....	Graph-ite { 1.70 1.97 2.10	Comb. { 0.56 .46 .47	6 H†	15.0	0.43	(12)
2	As cast.....			6 H†	7.9	.47	(12)
3	As cast.....			8 H†	12.9	.41	(12)
27. Fe-Cr-C, Cr-Steels (Stainless Steels)							
2	N.....	Cr, 11.7; C, 0.09	10 H†	32.0	0.53	(27)	
4	As received.....	Cr, 12.3; C, 0.25	10 H†	36.2	.46	(22)	
10	As received, R.....	Cr, 14.3; C, 0.1	10 H†	32.4	.53	(27)	
32. Fe-Ni-C, Ni-Steels							
1	As received.....	Ni, 2.93; C, 0.37	10 H†	31.2	0.43	(27)	
5	As received, R.....	Ni, 3.12; C, 0.12	1	22.8	.50	(25)	
6	As received, R.....	Ni, 3.25; C, 0.38	1	30.9	.61	(25)	
8A	830°/30 C <sub>f</sub> , 590°/120 C <sub>f</sub> ..	Ni, 3.41; C, 0.41 {	10	31.0	.36	(20)	
B	830°/15 Q <sub>o</sub> , 650°/120 C <sub>f</sub> ..		10	26.0	.31		
C	830°/30 C <sub>f</sub> , 810°/15 Q <sub>w</sub> (500°); S <sub>h</sub> W <sub>s</sub> 590°/60 C <sub>f</sub> ..		10	29.6	.36	(20)	
D	785°/60 C <sub>f</sub> .....		10	25.7	.36	(25)	
9A	As received, R.....	Ni, 3.56; C, 0.14	1	27.0	.54	(25)	
B	A 750°.....		1	26.5	.54	(25)	
13	As received, R.....	Ni, 4.70; C, 0.50	2	29.8	.47	(25)	
34. Fe-Ni-Cr-C, Ni-Cr-Steels							
9	Not stated.....	Ni, 2.93; Cr, 0.68; C (-)	8 H†	39.6	0.42	(29)	
13	Not stated.....	Ni, 3.33; Cr, 0.84; C (-)	8 H†	40.9	.49	(29)	
18	Not stated.....	Ni, 3.6; Cr, 0.6; C, 0.3	8 H†	36.2	.45	(15)	
38. Fe-Ni-Cr-V-C, Ni-Cr-V-Steels							
3	"Spec. S2 British Air Ministry".....	Ni, 3.3; Cr, 0.6; V, 0.1; C, 0.3	10 H†	42.8	0.45	(22)	
48. Ni, Commercial							
1	R <sub>h</sub> .....	Ni, 99.32	3 H†	20.5	0.40	(13)	
49. Ni-Cr							
1	R <sub>h</sub> .....	Cr, 19.04	10 H†	23.6	0.29	(27)	
50. Ni-Cu							
9	As received, R.....	Cu, 30.5	10 H†	21.2	0.38	(27)	
51. Ni-Cu-Mn							
1	As received, R.....	Cu, 28; Mn, 2.4	10 H†	25.1	0.40	(22)	

\* The key number is the same as the composition number where data are given for only one condition or treatment; while if data are given for more than one, the letters A, B, C, . . . are added to the composition numbers to distinguish the different treatments given.

† The number given in this column denotes the maximum number of millions of reversals of stress for which the fatigue stress was investigated. It does not denote the number of reversals at which the curve Fatigue Strength vs. Number of Reversals becomes parallel to N axis, although in many cases this has occurred at a smaller number of reversals.

‡ The H in column 4 denotes results obtained on the Haigh electromagnetic machine; in other cases the stresses are produced by inertia of unbalanced rotating weights or by calibrated springs.

§ Values will depend to some extent on the relative positions of the specimen and crystallographic a.i.s.

\* The key number is the same as the composition number where data are given for only one condition or treatment; while if data are given for more than one, the letters A, B, C, . . . are added to the composition numbers to distinguish the different treatments given.

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‡ The H in column 4 denotes results obtained on the Haigh electromagnetic machine; in other cases the stresses are produced by inertia of unbalanced rotating weights or by calibrated springs.

§ Values will depend to some extent on the relative positions of the specimen and crystallographic axis.



TABLE 3.—ENDURANCE LIMITS UNDER REVERSED BENDING STRESSES (ROTATING BEAM MACHINES)\*

Key No.†	Treatment	Approximate composition	Millions of reversals, 10 <sup>-6</sup> n†	Endurance limit, kg/mm <sup>2</sup> -F <sub>L0</sub> [Def. 17(b)]*	Endurance limit Tensile strength	Lit.
1. Al						
1	R.....	Al, 99.24	170	7.4	0.47	(19)
2. Al-Cu						
1	700° G <sub>s</sub> .....	Cu, 2.0	40	3.5	0.21	(17)
2	Tp.....	Cu, 4.6	100	11.3	.27	(16)
3	700° G <sub>s</sub> .....	Cu, 8.0	100	4.2	.31	(17)
4	G <sub>m</sub> .....	Cu, 12.0	7	4.2	.21	(15)
5	G <sub>s</sub> .....	Cu, 12.6	15	5.1	.42?	(15)
3. Al-Cu-Mg-Si						
1A	505°/7.5 Q <sub>b</sub> .....	Cu, 3.25; Mg, 0.7	400	9.8	0.27	(19)
B	Same, Tp { 495°/30 Q <sub>b</sub> (2 h) 370°/20 C <sub>f</sub> .....		400	8.4	.23	
C			200	7.7	.43	
2	F, W 500°/60 (niter) Q <sub>w</sub> 150°/60 (oil) C <sub>a</sub> .....	Cu, 3.6; Mg, 0.7	100	10.6	.31	(7)
3	F.....	Cu, 3.75; Mg, 0.26	10	8.5	.31	(7)
4	F, 500°/60 Q <sub>w</sub> , 100°/6 d.....	Cu, 3.88; Mg, 0.78	10	14.0	.38	(7)
5	R <sub>h</sub> , † 480°/Q <sub>w</sub> , V.....	Cu, 4.0; Mg, 0.50	2	16.6	.41	(13)
6	As received.....	Cu, 4.18; Mg, 0.66	12	14.9	.32	(14)
7	Tp, "duralumin".....	Cu, 4.3; Mg, 0.42	200	12.0	.28	(16)
8	R <sub>h</sub> , † 480° Q <sub>w</sub> , V.....	Cu, 5.0; Mg, 0.75	3	16.6	.40	(13)
9	R <sub>h</sub> , † 480° Q <sub>w</sub> , V.....	Cu, 6.0; Mg, 0.75	3	16.1	.36	(13)
4. Al-Cu-Ni-Mg						
1	R <sub>h</sub> , † "magnalite".....	Cu, 2; Ni, 1.5; Mg, 1	4	14.2		(13)
2	R <sub>h</sub> , 480° Q <sub>w</sub> .....	Cu, 4; Ni, 1; Mg, 1	10	15.5	0.43	(22)
3	R <sub>h</sub> , 480° Q <sub>w</sub> .....	Cu, 4; Ni, 1; Mg, 1.5	10	16.0	.45	(22)
4	R <sub>h</sub> , † 480° Q <sub>b</sub> , V.....	Cu, 4; Ni, 2; Mg, 1.5 "Y" alloy	3	14.2	.40	(13)
5	R <sub>h</sub> , † 480° Q <sub>b</sub> , V.....		3	16.3	.45	(13)
6	R <sub>h</sub> , † 520° Q <sub>b</sub> , V.....		10	16.0	.41	(13)
7	520°/360 Q <sub>b</sub> , V 5 d.....		20	11.0	.35	(9)
5. Al-Cu-Zn						
1	G <sub>m</sub> .....	Cu, 8.7; Zn, 5.3	6	7.1	0.37	(15)
2	G <sub>s</sub> .....	Cu, 9.5; Zn, 5.5	6	3.7	.26	(15)
6. Al-Mg						
1	R <sub>h</sub> , † ("aeromin").....	Mg, 6.2	3	10.3	0.30	(13)
7. Al-Mg-Si						
1	Tp.....	Mg, 0.55; Si, 0.56	50	8.5	0.28	(16)
8. Al-Si						
1	G <sub>s</sub> .....	Si, 5.0	50	4.2	0.32	(3)
2	G <sub>s</sub> M.....	Si, 8.0	50	5.6	.35	(3)
3	G <sub>m</sub> M.....	Si, 8.5	10	6.6	.34	(22)
4	G <sub>m</sub> M.....	Si, 11.0	10	6.7	.31	(22)
5	G <sub>s</sub> M.....	Si, 12.7	10	5.0	.29	(22)
7	G <sub>s</sub> M.....	Si, 13.0	50	5.8	.33	(3)
8	G <sub>m</sub> M.....	Si, 13.8	10	7.7	.42	(22)
10. Al-Zn-Cu						
1	705° G <sub>s</sub> .....	Zn, 7.7; Cu, 3	10	6.0	0.29	(7)
2	G <sub>s</sub> .....	Zn, 11.4; Cu, 2	8	3.7	.19	(15)
3	G <sub>m</sub> .....	Zn, 12.1; Cu, 2	8	4.7	.23	(15)
4	G <sub>s</sub> .....	Zn, 16.9; Cu, 3	70	4.1	.17	(17)
5	R <sub>h</sub> , † 350°/Q, V ("E" alloy)	Zn, 20; Cu, 2.5	2	15.3	.26	(13)
6	R <sub>h</sub> , † ("A" alloy)	Zn, 20.3; Cu, 3	2	13.7	.33	(13)
7	R <sub>h</sub> , † ("B" alloy)	Zn, 25; Cu, 3	2	16.5	.35	(13)
11. Cu, Electrolytic or Commercially Pure						
3A	As received	Cu, 99.99	100	11.3	0.31	(16)
B	R <sub>c</sub> W 650°/60 C <sub>f</sub>		100	7.4	.33	
4A	As received, D <sub>c</sub> .....	Cu, 99.98	68	8.8	.31	(16)
B	D <sub>c</sub> 650°/60 C <sub>f</sub> .....		C§	6.7	.31	
5	A.....	Cu, 99.96	30	8.2	.36	(9)
6A	E W 520°/30 C <sub>f</sub> .....	Cu, 99.90	100	7.1	.31	(20)
B	E W 700°/30 P <sub>w</sub> .....		400	7.0	.31	
C	E W 700°/30 P <sub>w</sub> D <sub>c</sub> (0.5 in. diam.).....		300	7.0	.18	

TABLE 3.—ENDURANCE LIMITS UNDER REVERSED BENDING STRESSES (ROTATING BEAM MACHINES). \*—(Continued)

Key No.†	Treatment	Approximate composition	$10^{-6}n$ †	$FL_0^*$	$\frac{FL_c}{UTS}$	Lit.	
12. Cu, Oxygenated							
1	R <sub>h</sub> , D (4 stages) intermediate anneals at 600°C...	0.04% O	50	12.9	0.49	(8)	
2		.05	50	12.3	.47	(8)	
3		.09	50	13.0	.49	(8)	
4		.24	50	11.6	.41	(8)	
13. Cu-Al, Al-Bronzes							
4A	As received, R.....	Al, 5.6	70	13.4	0.26	(16)	
B	R, 650°/60 C <sub>f</sub> .....		C§	10.7	.26		
6A	As received, R.....	Al, 9.1	70	17.2	.28	(16)	
B	R, 705°/60 C <sub>f</sub> .....		C§	12.9	.28		
7A	As received, R.....	Al, 10.0	50	20.7	.35	(16)	
B	R, 650°/60 C <sub>a</sub> .....		50	14.1	.32		
8A	G.....	Al, 9.8	60	15.5	.37	(19)	
B	G, 900° Q <sub>w</sub> 650°/30 C <sub>f</sub> .....		70	18.3	.34		
10	E W 900° Q <sub>w</sub> 620°/30 C <sub>f</sub> ...	Al, 10.1	60	23.9	.44	(19)	
11A	G <sub>s</sub> .....	Al, 10.0	10	19.0	.35	(5)	
B	G <sub>s</sub> , Q 850°, T <sub>p</sub> 630°.....		10	23.2	.37		
12A	As received, R.....	Al, 10.4	60	24.6	.35	(16)	
B	R, 650°/60 C <sub>f</sub> .....		C§	22.1	.35		
17. Cu-Ni							
1A	R <sub>c</sub> .....	Ni, 19.2	50	12.7	0.36	(16)	
B	R <sub>c</sub> , 760°/60 C <sub>f</sub> .....		C§	11.2	.36		
2	As received, R.....	Ni, 19.4	75	16.2	.34	(20)	
3	As received ("cupro-nickel")	Ni, 20.6	40	16.4	.46	(9)	
4A	As received, R <sub>h</sub> .....	Ni, 44.7	50	24.3	.49	(16)	
B	785°/60 C <sub>f</sub> ("constantan") ..		C§	24.3	.49		
5A	As received { R <sub>c</sub> .....	Ni, 44.8	40	30.3	.42	(16)	
B			R <sub>c</sub> , 790°/60 C <sub>f</sub> .....	10	19.7	.40	
18. Cu-Ni-Cr							
1A	As received, F.....	Ni, 34; Cr, 4	50	23.9	0.35	(16)	
B	815°/60 C <sub>f</sub> .....		C§	24.6	.35		
19. Cu-Ni-Sn							
1A	As received, D <sub>c</sub> .....	Ni, 29; Sn, 1	50	23.6	0.38	(16)	
B	815°/60 C <sub>f</sub> .....		C§	15.8	.38		
20. Cu-Ni-Zn							
1A	As received, R <sub>h</sub> .....	Ni, 20; Zn, 5	30	16.2	0.40	(16)	
B	760°/60 C <sub>f</sub> .....		C§	14.6	.40		
2	As received, D <sub>c</sub> ("German silver").....	Ni, 11; Zn, 29	60	12.0	.29	(16)	
21. Cu-Sn, Bronzes							
2	As received, R(P-bronze)....	Sn, .2	50	20.4	0.44	(16)	
4A	As received { R <sub>c</sub> .....	Sn, 4	30	15.9	.40	(16)	
B			R <sub>c</sub> 650°/60 C <sub>f</sub> .....	30	15.9	.47	(16)
5A	P <sub>w</sub> , D (¾ in. diam.) 700°/30	Sn, 4.9	1000	16.2	.50	(20)	
	P <sub>w</sub> , D (¾ in. diam.) 700°/30			19.0	.32		
	P <sub>w</sub> .....						
B	Same, D <sub>c</sub> , 1 in. diam.....		400				
6A	As received, D <sub>c</sub> .....	Sn, 5.1	70	19.0	.43	(16)	
B	650°/60 C <sub>f</sub> .....		C§	14.6	.43		
7A	As received { R <sub>c</sub> .....	Sn, 10.6	30	19.0	.33	(16)	
B			R <sub>c</sub> , 590°/60 C <sub>f</sub> .....	30	19.0	.40	
22. Cu-Zn, Brasses							
1A	As received { D <sub>c</sub> .....	Zn, 19	100	16.2	0.29	(16)	
B			D <sub>c</sub> 235°/60 C <sub>f</sub> .....	100	18.3		.32
C			D <sub>c</sub> 540°/60 C <sub>f</sub> .....	100	12.3		.40
2A	As received, D <sub>c</sub> .....	Zn, 26.6	20	12.0	.34	(16)	
B	650°/60 C <sub>f</sub> .....		C§	11.1	.34		
5A	As received { R <sub>c</sub> .....	Zn, 30	100	12.3	.24	(16)	
B			R <sub>c</sub> 230°/90 C <sub>f</sub> .....	100	14.1	.27	
C			R <sub>c</sub> 235°/90 C <sub>f</sub> .....	100	14.1	.27	
D			R <sub>c</sub> 260°/90 C <sub>f</sub> .....	100	15.2	.29	
E			R <sub>c</sub> 650°/90 C <sub>f</sub> .....	100	22.1	.33	
6	A.....	Zn, 30.1	60	14.2	.45	(9)	
8	As received, R <sub>c</sub> .....	Zn, 34.6	12	16.5	.43	(14)	
9	R } Naval brass..... {	Zn, 38.27	600	14.8	.31	(19)	
10							R <sub>h</sub> } Zn, 38.3
11	G, W 780°, E 700° (1 in.) W 550°/30 P <sub>w</sub> , D (¾ in.) W 550°/30 P <sub>w</sub> .....	Zn, 39.6	400	20.4	.41	(20)	

TABLE 3.—ENDURANCE LIMITS UNDER REVERSED BENDING STRESSES (ROTATING BEAM MACHINES). \*—(Continued)

Key No.	Treatment	Approximate composition	10 <sup>-6</sup> n†	FL <sub>0</sub> *	FL <sub>0</sub> UTS	Lit.	
22. Cu-Zn, Brasses.—(Continued)							
12A B	G, W 780°, E 700° (1 in.), 550°/30 P <sub>w</sub>	Zn, 40.1	500	15.5	0.41	(20)	
	D, ¾ in. D <sub>c</sub> , ½ in.		500	18.3	.27		
13A B C	Q <sub>i</sub> Tp { 250° 341° 425° } Muntz metal	Zn, 40.1	60	11.3	.21	(16)	
			100	13.0	.23		
			100	12.7	.27		
15A B	As received, R <sub>h</sub> 650°/60 C <sub>f</sub> , (Mn bronze)	Zn, 40.1	70 C§	13.0 11.6	.24 .24	(16)	
17	960° G (Mn bronze).....	Zn, 40.9	150	12.0	.24	(19)	
22.5. Cu-Zn-Pb, Lead Brasses							
1	D <sub>d</sub> .....	Zn, 38.3; Pb, 0.06	50	14.4	0.35	(8)	
2	D <sub>d</sub> .....	Zn, 37.9; Pb, 0.53	50	16.2	.40	(8)	
3	D <sub>d</sub> .....	Zn, 37.9; Pb, 1.58	50	16.2	.40	(8)	
4	D <sub>d</sub> .....	Zn, 37.8; Pb, 2.61	50	15.1	.37	(8)	
5	D <sub>d</sub> .....	Zn, 37.1; Pb, 3.43	50	13.7	.34	(8)	
23. Fe, Commercially Pure							
1A	A 1000°/30 C <sub>f</sub> (Armco iron).	C, 0.012	100	19.8	0.67	(9)	
2A B	As received, A <sub>b</sub> A <sub>b</sub> , W 815°/15 Q <sub>w</sub>	C, 0.02	100	18.3	.61	(20)	
	Ingot iron		100	23.2	.66		
3A B	R <sub>h</sub> ..... 900°/60 Q <sub>w</sub> .....	C, 0.023	100 10	16.5 17.6	.53 .54	(16)	
6	F.....	C, 0.045 C, 0.06	100	16.2	.49	(20)	
7	As received		12	18.4	.51	(14)	
24. Fe-C, Carbon Steels							
2A B	N 900°..... N 900°, W 760° Q <sub>w</sub> .....	C, 0.11	10 10	18.4 27.8	0.44 .58	(14)	
3	N 850°.....	C, 0.13	250	25.7	.53	(9)	
5A B C D E F	R <sub>h</sub> 890° Q <sub>o</sub> ..... 200°..... 300°..... Same, T <sub>p</sub> { 400°..... 500°..... 600°.....	C, 0.14	10 10 10 10 10 10	34.4 33.6 32.7 29.6 29.6 25.4	.45 .44 .45 .44 .45 .43	(15)	
6	As received.....	C, 0.14	100	17.4	.43	(16)	
7	A.....	.15		18.0	.52	(29)	
8	N 900°.....	.15	10	18.4	.55	(14)	
11	R 900°, H 770°.....	C, 0.17	12	29.4	.47	(9)	
12	R <sub>h</sub> .....	.18	100	19.7	.46	(21)	
14	R 880°, H 770°.....	.19	12	28.0	.46	(9)	
15A B C	As received, D <sub>c</sub> ..... D <sub>c</sub> , 845°/15 C <sub>f</sub> ..... D <sub>c</sub> , 700°/15 C <sub>f</sub> .....	C, 0.20	100 100 100	28.8 17.6 20.4	.47 .43 .51	(21)	
16	As received.....	C, 0.20	12	22.1	.45	(14)	
17	R <sub>h</sub> .....	C, 0.21	100	23.4	.47	(16)	
19A B C D E F G H J K	As received..... 870°/30 C <sub>f</sub> (v. also Figs. 1 and 2)..... 870°/30 C <sub>a</sub> ..... 870°/30 Q <sub>o</sub> { 700°/30 C <sub>f</sub> ..... 590°/30 C <sub>f</sub> ..... 480°/30 C <sub>f</sub> ..... 370°/30 C <sub>f</sub> ..... 900°/60 Q <sub>w</sub> { 670°/60 C <sub>f</sub> ..... 540°/60 C <sub>f</sub> ..... 430°/60 C <sub>f</sub> .....	C, 0.24	10 10 10 10 10 10 10 10 10 10	17.9 15.8 17.2 17.9 17.9 20.7 19.3 21.4 22.2 20.7	.42 .41 .40 .42 .39 .44 .40 .46 .40 .37	(16)	
20	As received, R.....	C, 0.25	12	19.5	.43	(9)	
21	F.....	C, 0.25	10	25.0	.47	(16)	
22A	D <sub>c</sub> .....	C, 0.26	12	30.1	.47	(1)	
22B C D	D <sub>c</sub> { B 250°..... B 400°..... B 550°.....	C, 0.26	12 12 12	29.0 29.9 28.4	.46 .48 .49	(1)	
24		A 650°.....	C, 0.29	100	21.1	.43	(16)
26		As received, R <sub>h</sub> .....	.30	12	26.3	.45	(9)
27	830°/Q <sub>o</sub> , A 650°.....	.31	100	21.1	.42	(16)	
28	N 850°.....	.31	12	20.2	.36	(14)	
29	As received, R <sub>h</sub> .....	.31	12	33.9	.51	(9)	

TABLE 3.—ENDURANCE LIMITS UNDER REVERSED BENDING STRESSES (ROTATING BEAM MACHINES). \*—(Continued)

Key Not.	Treatment	Approximate composition	10 <sup>-6</sup> n†	FL <sub>0</sub> *	FL <sub>0</sub> UTS	Lit.
<b>24. Fe-C, Carbon Steels.—(Continued)</b>						
30A B C D E F	R <sub>h</sub> 870° Q <sub>w</sub> 200° 300° Same, Tp { 400° 500° 600° }	C, 0.32	10 10 10 10 10 10	58.5 41.4 39.9 45.5 42.1 39.3	0.41 .43 .46 .44 .42 .50	(15)
31	850°/15 C <sub>a</sub>	C, 0.33	250	27.6	.47	(11)
35A B	N 850° 850°/Q <sub>o</sub> , Tp 600°	C, 0.36	12 12	26.8 29.9	.45 .41	(9)
36	A	C, 0.37		21.1	.37	(29)
37B C	810°/15 C <sub>fo</sub> 845°/15 Q <sub>w</sub> , 570° C <sub>a</sub> (sorbite)	C, 0.37	100 100	23.2 40.1	.46 .56	(20)
39A B C D E F G H J K L	845°/30 Cf (v. also Figs. 1 and 2) 845°/30 C <sub>a</sub> 930°/120 Q <sub>o</sub> , 845°/30 Cf 670°/30 Cf 845°/30 Q <sub>o</sub> { 670°/30 Cf 540°/30 Cf 430°/30 Cf 980°/300 Q <sub>o</sub> , 845°/60 Cf 670°/60 Cf 590°/60 Cf 540°/60 Cf 430°/60 Cf	C, 0.38	10 10 10 10 10 10 10 10 10 10 10	21.4 22.5 20.7 23.6 23.6 23.6 20.7 25.0 27.8 29.2 27.1	.44 .41 .41 .42 .39 .37 .42 .43 .46 .43 .40	(20)
41	As received	C, 0.40	12	29.1	.46	(9)
43	As received	.42	12	27.3	.42	(9)
47A B 49	N H <sub>o</sub> 850°, Tp <sub>o</sub> 600° A 870°	C, 0.45 .48	12 12 100	28.8 34.9 24.6	.44 .46 .43	(9) (16)
50A B C D E F G H J	815°/30 C <sub>a</sub> 925°/20 C <sub>a</sub> 925°/20 C <sub>a</sub> , 775° Q <sub>w</sub> , 650° Cf 925°/20 C <sub>a</sub> , 790°/15 Q <sub>o</sub> 760°/30 C <sub>a</sub> 650°/30 C <sub>a</sub> Same, Tp { 540°/30 C <sub>a</sub> 430°/30 C <sub>a</sub> 315°/30 C <sub>a</sub>	C, 0.49	100 100 100 100 100 100 100 100 100	22.5 23.2 33.8 45.7 26.0 35.2 40.0 45.0 47.8	.42 .36 .50 .51 .43 .53 .53 .53 .54	(20)
52A B	845°/15 C <sub>a</sub> Same, 790°/15 Q <sub>w</sub> , 650° C <sub>a</sub>	C, 0.52	100 100	29.5 38.7	.42 .49	(20)
53B C D E F G H	760°/30 C <sub>a</sub> 650°/30 C <sub>a</sub> 925°/20 C <sub>a</sub> , 540°/30 C <sub>a</sub> 790°/15 Q <sub>o</sub> { 425°/30 C <sub>a</sub> 315°/30 C <sub>a</sub> 205°/30 C <sub>a</sub>	C, 0.53	100 100 100 100 100 100 100	27.4 37.3 41.5 45.7 47.1 47.8 47.1	.44 .56 .53 .50 .52 .51 .52	(20)
55A B C D	400° Q <sub>o</sub> , Tp { 450° 500° 550° }	C, 0.60	10 10 10 10	74.0 65.4 59.7 59.2	.43 .46 .48 .50	(22)
56	N 810°	C, 0.60	10	28.4	.37	(14)
60	N 800°	C, 0.65	12	32.3	.41	(9)
61	Not stated	.71	10	30.2	.34	(14)
63	A 730°	.77	100	27.4	.35	(16)
65A B	790°/30 Cf 800°/120 C <sub>a</sub>	C, 0.81	10 10	22.2 27.1	.35 .35	(16)
66B C D	870°/ { 790°/15 Cf 15 C <sub>a</sub> { 790°/15 Q <sub>o</sub> { 650°/30 C <sub>a</sub> 455°/30 C <sub>a</sub>	C, 0.93	100 100 100	21.4 39.4 68.9	.36 .49 .52	(20)
67	790°/60 Cf	C, 0.97	10	22.9	.37	(16)
68	790°/30 Cf, 790°/30 Q <sub>o</sub>	C, 1.02	10	73.9		(20)
69A B	795°/15 { 860°/15 C <sub>fo</sub> C <sub>fo</sub> { 800° Q <sub>o</sub> , 460°/15 C <sub>a</sub>	C, 1.20	100 100	35.2 64.7	.43 .51	(20)



TABLE 3.—ENDURANCE LIMITS UNDER REVERSED BENDING STRESSES (ROTATING BEAM MACHINES). \*—(Continued)

Key No.†	Treatment	Approximate composition	$10^{-6}\epsilon\eta$	$FL\sigma^*$	$\frac{FL\sigma}{UTS}$	Lit.
<b>27. Fe-Cr-C, Cr-Steels.—(Continued)</b>						
13A	900°/60 Q <sub>w</sub> , 480°/60 C <sub>a</sub> ....	Cr, 16; C, 0.6	10	80.5	0.57	(16)
B	As received, A.....		10	38.3	.55	

27. Fe-Cr-C, Cr-Steels.—(Continued)

3A	870°/60 C <sub>f</sub> .....	Cr, 0.76; Mo, 0.18; C, 0.39	10	27.1	0.45	(16)
B	870°/60 Q <sub>w</sub> { 480°/60 C <sub>f</sub> ...		10	47.9	.56	
C	590°/60 C <sub>f</sub> .....		10	48.1	.50	
5A	870°/60 C <sub>f</sub> .....	Cr, 0.85; Mo, 0.20; C, 0.31	10	25.7	.44	(16)
B	870°/60 Q <sub>w</sub> { 480°/60 C <sub>f</sub> ...		10	51.0	.44	
C	590°/60 C <sub>f</sub> .....		10	44.6	.45	
8	To PL $\cong$ 42.....	Cr, 0.95; Mo, 0.1; C, 0.4	100	33.0	.51	(16)
12A	870°/60 C <sub>f</sub> .....	Cr, 1.0; Mo, 0.2; C, 0.50	10	34.8	.45	(16)
B	870°/60 Q <sub>w</sub> { 480°/60 C <sub>f</sub> ...		10	61.9	.51	
C	590°/60 C <sub>f</sub> .....		10	53.1	.49	
13	To PL $\cong$ 77.....	Cr, 1; Mo, 0.1; C, 0.4	100	47.5	.48	(16)

### 30. Fe-Cr-V-C, Cr-V-Steels

3	H, Tp.....	Cr, 0.95; V, 0.2 ; C, 0.44	10	51.7	0.52	(1)
4A	900°/60 C <sub>f</sub> .....	Cr, 1.0 ; V, 0.2; C, 0.55	10	31.3	.44	(16)
B	900°/60 Q <sub>w</sub> { 480°/60 C <sub>f</sub> ...		10	66.4	.47	
C	590°/60 C <sub>f</sub> .....		10	64.7	.56	
5	Sv.....	Cr, 1.0; V, 0.16; C, 0.45	10	32.0	.44	(16)
6	To PL $\cong$ 42.....	Cr, 1.2; V, 0.2; C, 0.24	100	25.4	.45	(16)
7	To PL $\cong$ 77.....	Cr, 1.5; V, 0.2 ; C, 0.53	100	47.0	.46	(16)
8	850° Q <sub>o</sub> , 650° C <sub>A</sub> .....	Cr, 1.5; V, 0.33; C, 0.46	12	43.3	.49	(14)
9	As received, R <sub>B</sub> .....	Cr, 13.5; V, 0.3; C, 0.03	200	28.2	.49	(19)

### 32. Fe-Ni-C, Ni-Steels

2A	N 810°.....	Ni, 3.0; C, 0.4	10	33.9	0.43	(14)
B	850° Q <sub>o</sub> , 620° Q <sub>w</sub> .....		10	34.7	.44	
4	As taken from service <sup>†</sup> .....	Ni, 3.1; C, 0.4	10	31.3	.47	(16)

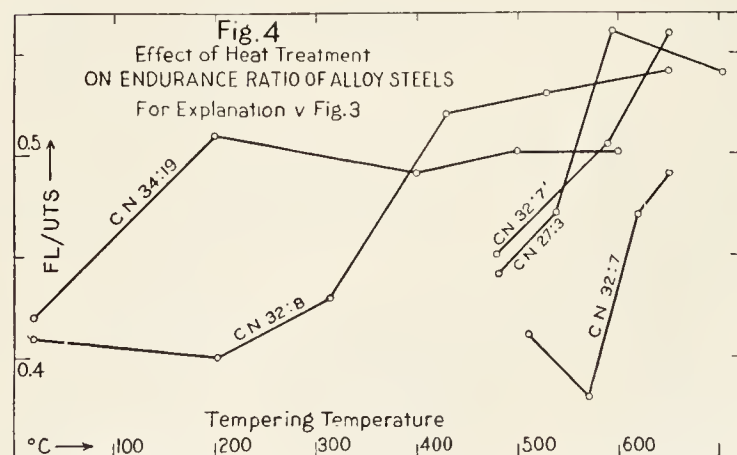
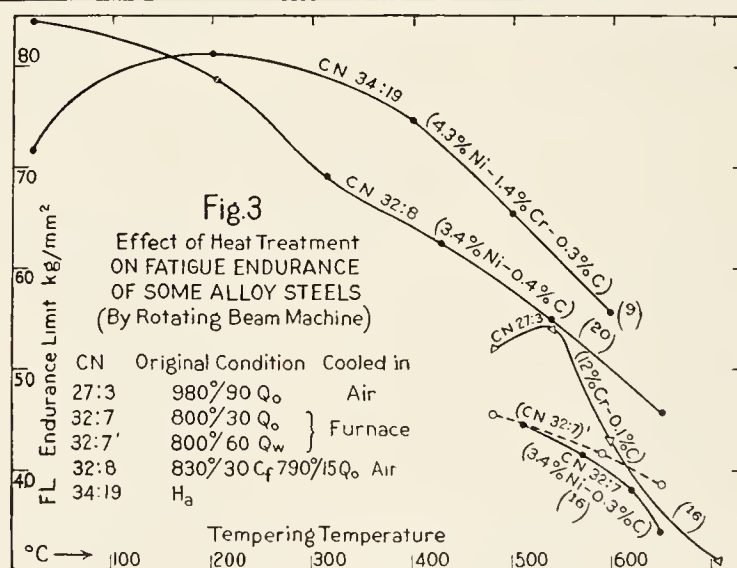


TABLE 3.—ENDURANCE LIMITS UNDER REVERSED BENDING STRESSES (ROTATING BEAM MACHINES). \*—(Continued)

Key No.†	Treatment	Approximate composition	10 <sup>-6</sup> n†	FL <sub>0</sub> * UTS	Lit.
<b>32. Fe-Ni-C, Ni-Steels.—(Continued)</b>					
7A	900°/120 Q <sub>0</sub> , 800°/30 C <sub>f</sub> ....	Ni, 3.4; C, 0.3	10	28.5	0.48 (16)
C	800°/60 C <sub>f</sub> .....		10	34.8	.48
D	800°/30 C <sub>a</sub> .....		10	29.9	.47
E	800°/30 Q <sub>0</sub> { 650°/30 C <sub>f</sub> ....	(v. also Figs. 3 and 4)	10	33.4	.49
F	620°/30 C <sub>f</sub> ....		10	38.0	.47
G	800°/60 Q <sub>0</sub> , 590°/60 C <sub>f</sub> ....		10	33.7	.49
H	800°/30 Q <sub>0</sub> { 570°/30 C <sub>f</sub> ....		10	41.8	.38
J	510°/30 C <sub>f</sub> ....		10	44.6	.41
K	800°/60 Q <sub>0</sub> , 480°/30 C <sub>f</sub> ....		10	38.3	.46
L	650°/60 C <sub>f</sub> ....		10	38.7	.56
M	800°/60 Q <sub>w</sub> { 590°/60 C <sub>f</sub> ....		10	41.5	.51
N	480°/60 C <sub>f</sub> ....		10	45.3	.45
8A	830°/30 C <sub>f</sub> , { 590°/120 C <sub>f</sub> ....	Ni, 3.4; C, 0.4	100	45.0	.52 (20)
B	830°/15 Q <sub>0</sub> { 650°/120 C <sub>f</sub> ....		100	44.3	.53
C	830°/30 C <sub>f</sub> , 810°/15, C to 500°, Q <sub>w</sub> , S <sub>h</sub> , W <sub>s</sub> 590°/60 C <sub>f</sub> ....		100	45.0	.55
D	785°/60 C <sub>f</sub> .....		100	38.0	.53
E	830°/30 C <sub>f</sub> , 790°/15 Q <sub>0</sub> ....	(v. also Figs. 3 and 4)	100	84.4	.41
F	205°/30 C <sub>a</sub> .....		100	78.8	.40
G	315°/30 C <sub>a</sub> .....		100	68.9	.43
H	Same, T <sub>p</sub> { 430°/30 C <sub>a</sub> .....		100	62.6	.52
J	540°/30 C <sub>a</sub> .....		100	54.8	.53
K	650°/30 C <sub>a</sub> .....		100	45.7	.54
10A	790°/60 C <sub>f</sub> .....	Ni, 3.6; C, 0.4	10	35.9	.45 (16)
B	790°/30 Q <sub>0</sub> , 620°/30 C <sub>f</sub> ....		10	41.8	.48
C	790°/60 Q <sub>0</sub> , 480°/60 C <sub>f</sub> ....		10	46.7	.56
D	590°/60 C <sub>f</sub> ....		10	50.6	.54
E	790°/60 Q <sub>w</sub> { 540°/60 C <sub>f</sub> ....		10	52.4	.50
F	480°/60 C <sub>f</sub> ....		10	52.0	.48
11	To PL ≅ 42.....	Ni, 3.7; C, 0.3	100	32.4	.50 (16)
14	N 860°, 760° Q <sub>w</sub> .....	Ni, 4.8; C, 0.14	10	41.8	.44 (14)
15	N 860°.....	Ni, 5.10; C, 0.13	6	37.7	.66 (28)
16	R, H 730°.....	Ni, 5.76; C, 0.11	12	41.5	.51 (1)

**34. Fe-Ni-Cr-C, Ni-Cr-Steels**

		Ni	Cr	C			
1	To PL ≅ 42.....	0.47	1.10	0.43	100	27.6	0.42 (16)
4	Sv.....	1.41	0.81	.46	10	44.6	.45 (16)
5	To PL ≅ 77.....	1.45	1.10	.41	100	38.6	.41 (16)
6A	845°/60 C <sub>f</sub> .....	1.75	0.99	.49	10	35.1	.43 (16)
B	845°/60, Q <sub>w</sub> T <sub>p</sub> { 590°.....				10	50.6	.50
C	480°.....				10	59.4	.51
10	R 850°, H 770°.....	3.00	.48	.19	12	48.8	.47 (9)
11	R 840°, H 770°.....	3.15	.58	.20	12	46.5	.38 (9)
12A	To PL ≅ 42.....	3.18	.96	.33	100	28.1	.39 (16)
B	To PL ≅ 77.....				100	42.2	.45
14A	A, 830° Q <sub>0</sub> , 330° Q <sub>0</sub> .....	3.33	.87	.24	100	47.8	.49 (20)
B	A, 830°/30 Q <sub>0</sub> , 790° { 650°/60 C <sub>f</sub> ....				100	45.7	.57
C	Q <sub>0</sub> T <sub>p</sub> { 650°/60 Q <sub>w</sub> ....				100	47.1	.59
D	A 830°/30 C <sub>a</sub> , 790°/30 C <sub>f</sub> ....				100	34.4	.56
15A	830°/30 C <sub>f</sub> , 790°/15 Q <sub>0</sub> { 425°/30 C <sub>a</sub> ....	3.33	.18	.41	10	53.5	.46 (20)
B	650°/30 C <sub>a</sub> ....				10	52.1	.59
16	850° Q <sub>0</sub> T <sub>p</sub> 600°.....	3.45	.76	.32	12	44.2	.45 (14)
17	H, T <sub>p</sub> .....	3.48	.78	.32	12	52.0	.50 (9)
19A	H <sub>a</sub> (fully).....	4.30	1.40	.30	12	71.6	.42 (9)
B	200° { (v. also Figs. 3 and 4) "Air-hardening steel"				12	81.2	.51
C	400° {				12	74.8	.49
D	500° {				12	65.3	.50
E	600° {				12	55.6	.50
20	R 820°, H 760°.....	4.65	0.29	.16	12	47.2	.50 (22)
21A	R <sub>h</sub> (2 passes); R <sub>c</sub> .....	19.7	8.31	.33	10	38.7	.48 (20)
B	Same, W 940°/30 C <sub>f</sub> (stainless steel, cyclops metal).....				80	39.4	.50

**35. Fe-Ni-Cr-Cu-C, Ni-Cr-Cu-Steels (Stainless Steels)**

1	As received, A.....	Ni, 12; Cr, 19; C, 0.8	10	46.0	0.53 (16)
2	As received, A.....	Ni, 16; Cr, 16; C, 0.4	10	45.0	.49 (16)
3	As received, A.....	Ni, 23; Cr, 5.4; C, 0.25	10	35.2	.52 (16)
4	As received, A.....	Ni, 25; Cr, 18; C, 0.4	10	38.0	.46 (16)
5	As received, A.....	Ni, 26; Cr, 17.3; C, 0.7	10	39.0	.52 (16)
6	As received, A.....	Ni, 28; Cr, 8.4; C, 0.45	10	41.1	.53 (16)

TABLE 3.—ENDURANCE LIMITS UNDER REVERSED BENDING STRESSES (ROTATING BEAM MACHINES). \*—(Continued)

Key No.†	Treatment	Approximate composition	10 <sup>-6</sup> n†	FL <sub>0</sub> * UTS	Lit.
<b>37. Fe-Ni-Cr-Mo-C, Ni-Cr-Mo-Steels</b>					
9	Not stated.....	Ni, 4.8; Cr, 1; Mo, 0.9; C, 0.3	12	51.2	0.42 (14)
<b>38. Fe-Ni-Cr-V-C, Ni-Cr-V-Steels</b>					
3	To Specification S2, British Air Ministry.....	Ni, 3.3; Cr, 0.6; V, 0.1; C, 0.3	12	53.5	0.56 (22)
<b>39. Fe-Ni-Mo-C, Ni-Mo-Steels</b>					
1A	To PL ≅ 42.....	Ni, 1.70; Mo, 0.12; C, 0.4	100	32.8	0.44 (16)
B	To PL ≅ 77.....		100	40.1	.43
<b>42. Fe-Si-Mn-C, Si-Mn-Steels</b>					
1A	To PL ≅ 42.....	Si, 2.0; Mn, 0.65; C, 0.55	100	34.5	0.44 (16)
B	To PL ≅ 77.....	(Spring steels)	100	43.6	.39
<b>43. Fe-V-C, V-Steels</b>					
1A	870°/60 C <sub>a</sub> , 840°/45 Q <sub>w</sub> , 650°/60, C to 480° C <sub>a</sub> ....	V, 0.16; C, 0.57	100	40.1	0.53 (19)
B	870°/60 C <sub>a</sub> , 650°/30 C <sub>a</sub> , 870°/120 Q <sub>w</sub> , 700°/60 C <sub>a</sub> ....		100	36.6	.51
C	870°/60 C <sub>a</sub> , 650°/60 C <sub>a</sub> ....		50	43.0	.54
<b>44. Mg, Commercial</b>					
1	E.....	Mg, 99.96	150	5.5	0.24 (19)
2	R <sub>h</sub> .....	Mg, 99.89	20	7.1	.30 (22)
<b>45. Mg-Al</b>					
1	E.....	Al, 4.2	600	8.4	0.34 (19)
2	E.....	Al, 4.4	100	10.6	.39 (19)
3	R <sub>h</sub> .....	Al, 6.0	20	11.3	.36 (22)
4	E.....	Al, 6.70	600	9.2	.31 (19)
5	E.....	Al, 6.80	80	10.6	.35 (19)
6A	F, longitudinal.....	Al, 8.7	60	10.5	.36 (19)
B	F, transverse.....		60	9.1	.43
C	As cast.....		60	8.8	.45
<b>46. Mg-Cu</b>					
1	E.....	Cu, 9.65	600	7.7	0.28 (19)
<b>47. Mg-Zn</b>					
1	As received, electron metal..	Zn, 4.38	200	12.0	0.47 (19)
<b>48. Ni, Commercial</b>					
1	R <sub>h</sub> .....	Ni, 99.32	12	20.5	0.40 (13)
2A	As received, R <sub>h</sub> .....	Ni, 99.07	400	16.9	.40 (16)
2B	760°/60 C <sub>f</sub> .....		300	22.2	.41
3	D <sub>a</sub> 870° C <sub>f</sub> .....	Ni, 99+	200	19.7	.41 (20)
4A	As received, R <sub>c</sub> , A 288°.....	Ni, 98.95	100	28.1	.24 (16)
B	288°/60 C <sub>f</sub> .....		60	28.1	.24
C	288°/60 C <sub>f</sub> .....		70	28.1	.25
D	R <sub>c</sub> W { 595°/60 C <sub>f</sub> .....		70	34.4	.34
E	760°/60 C <sub>f</sub> .....		30	19.0	.37
F	870°/60 C <sub>f</sub> .....		50	17.9	.36
5A	As received { D <sub>c</sub> .....	Ni, 98.7	60	26.4	.37 (16)
B	D <sub>c</sub> , 870°/60 C <sub>f</sub> .....		60	20.4	.37
<b>50. Ni-Cu</b>					
1A	As received, R <sub>c</sub> .....	Cu, 21.3	500	21.1	0.34 (16)
B	R <sub>c</sub> , 870°/60 C <sub>f</sub> .....		50	18.3	.33
2A	As received, R <sub>c</sub> .....	Cu, 23.6	100	23.9	.35 (16)
B	R <sub>c</sub> , 870°/60 C <sub>f</sub> .....		C§	20.7	.35
3	R <sub>h</sub> , A 760°.....	Cu, 28	70	26.4	.43 (16)
4	As received, R <sub>h</sub> .....	Cu, 27.3	500	22.5	.36 (20)
5A	As received { D <sub>c</sub> .....	Cu, 28.6	60	24.3	.37 (16)
B	D <sub>c</sub> , 290°/60 C <sub>f</sub> .....		60	25.3	.37
C	D <sub>c</sub> , 870°/60 C <sub>f</sub> .....		60	19.7	.35
6	As received, R <sub>h</sub> .....	Cu, 29.7	100	29.5	.47 (16)
7A	R <sub>h</sub> .....	Cu, 29.5	400	26.7	.42 (16)
B	870°/60 C <sub>f</sub> .....		C§	22.9	.42
8	R <sub>h</sub> .....	Cu, 30	75	26.3	.42 (18)
10A	As received, R <sub>h</sub> .....	Cu, 44.2	50	18.7	.40 (16)
B	Same, 815°/60 C <sub>f</sub> .....		40	16.9	.38
<b>51. Ni-Cu-Mn</b>					
2A	As received { R <sub>h</sub> .....	Cu, 26.2; Mn, 4.3	60	27.4	0.43 (16)
B	R <sub>h</sub> , 870°/60 C <sub>f</sub> .....		C§	26.6	.43

\* Stresses computed by usual formulae of beam theory. † See footnotes to corresponding columns in Table 2. ‡ 22.5 mm diam. § C, calculated value. (Author assumes FL<sub>0</sub>/UTS the same for the different treatments.) ¶ Battleship propeller shaft.



TABLE 4.—ENDURANCE LIMITS UNDER REVERSED PLANE BENDING STRESSES (UPTON-LEWIS MACHINE)\*

Key No.†	Treatment	Approximate composition	Millions of reversals, 10 <sup>-6</sup> n†	Endurance limit, kg/mm <sup>2</sup> FL <sub>0</sub> [Def. 17(b)]*	Endurance limit Tensile strength	Lit.	
23. Fe, Commercially Pure							
2A	As received, A <sub>B</sub> (ingot iron).	C, 0.02	2	16.2	0.54	(20)	
24. Fe-C, C-Steels							
37B	810°/15 C <sub>fo</sub> .....	C, 0.37	2	21.0	0.42	(20)	
40	870° Q <sub>w</sub> , 420°/60 C <sub>a</sub> .....	C, 0.40	2	48.0	.40	(8)	
44A	875° Q <sub>o</sub> { 400°/60 C <sub>a</sub> ..... 450°/60 C <sub>a</sub> .....	C, 0.44	2	62.5	.48	(8)	
B			2	60.0	.50		
50B	925°/20 C <sub>a</sub> .....	C, 0.49	2	19.5	.31	(20)	
C	Same, 775° Q <sub>w</sub> , 650° C <sub>f</sub> .....		2	27.5	.40		
52A	845°/15 C <sub>a</sub> .....	C, 0.52	2	22.5	.33	(20)	
B	Same, 790°/15 Q <sub>w</sub> , 650° C <sub>a</sub> .....		2	31.0	.40		
66B	870°/15 C <sub>a</sub> { 790°/15 C <sub>f</sub> ..... 790°/15 Q <sub>o</sub> { 650°/30 C <sub>a</sub> ..... 455°/30 C <sub>a</sub> .....	C, 0.93	2	20.0	.34	(20)	
C			2	31.0	.38		
D			2	48.5	.37		
69A	795°/15 C <sub>f</sub> , 866°/15 C <sub>fo</sub> .....	C, 1.20	2	31.5	.38	(20)	
26. Fe-Ce-C, Ce-Steels							
1A	870° Q <sub>w</sub> { 360°/60 C <sub>a</sub> ..... 420°/60 C <sub>a</sub> .....	Ce, 0.4-0.6; C, 0.38	2	56.0	0.44	(8)	
B			2	49.5	.45		
27. Fe-Cr-C, Cr-Steels							
1A	900° Q <sub>o</sub> { 425°/60 C <sub>a</sub> ..... 525°/60 C <sub>a</sub> ..... 625°/60 C <sub>a</sub> .....	Cr, 0.94; C, 0.35	2	55.0	0.40	(8)	
B			2	56.0	.51		
C			2	40.0	.45		
28. Fe-Cr-Ce-C, Cr-Ce-Steels							
1A	900° Q <sub>o</sub> { 425°/60 C <sub>a</sub> ..... 525°/60 C <sub>a</sub> ..... 625°/60 C <sub>a</sub> .....	Cr, 0.98; Ce, 0.41-0.50; C, 0.41	2	59.0	0.39	(8)	
B			2	50.5	.48		
C			2	41.5	.49		
29. Fe-Cr-Mo-C, Cr-Mo-Steels							
1A	925° Q <sub>o</sub> { 425°/60 C <sub>a</sub> ..... 525°/60 C <sub>a</sub> ..... 630°/60 C <sub>a</sub> .....	Cr, 0.55; Mo, 0.39; C, 0.42	2	67.0	0.46	(8)	
B			2	64.5	.53		
C			2	55.5	.61		
2A	925° Q <sub>w</sub> { 425°/60 C <sub>a</sub> ..... 525°/60 C <sub>a</sub> ..... 625°/60 C <sub>a</sub> .....	Cr, 0.73; Mo, 0.28; C, 0.15	2	43.0	.39	(8)	
B			2	48.5	.55		
C			2	36.5	.54		
4A	850° Q <sub>w</sub> { 425°/60 C <sub>a</sub> ..... 525°/60 C <sub>a</sub> ..... 625°/60 C <sub>a</sub> .....	Cr, 0.79; Mo, 0.34; C, 0.22	2	56.2	.58	(8)	
B			2	52.5	.55		
C			2	40.0	.49		
6A	820° Q <sub>o</sub> { 425°/60 C <sub>a</sub> ..... 525°/60 C <sub>a</sub> ..... 625°/60 C <sub>a</sub> .....	Cr, 0.88; Mo, 0.30; C, 0.40	2	69.0	.48	(8)	
B			2	61.1	.52		
C			2	49.0	.52		
7A	900° Q <sub>o</sub> , 525°/60 C <sub>a</sub> .....	Cr, 0.89; Mo, 0.36; C, 0.41	2	60.0	.48	(8)	
B			2	45.5	.50		
9A	815° Q <sub>o</sub> { 425°/60 C <sub>a</sub> ..... 525°/60 C <sub>a</sub> ..... 625°/60 C <sub>a</sub> .....	Cr, 0.95; Mo, 0.39; C, 0.52	2	70.5	.48	(8)	
B			2	64.5	.49		
C			2	42.0	.45		
10A	900° Q <sub>o</sub> { 425°/60 C <sub>a</sub> ..... 525°/60 C <sub>a</sub> ..... 625°/60 C <sub>a</sub> ..... 820° C <sub>a</sub> .....	Cr, 0.95; Mo, 0.68; C, 0.40	2	68.0	.44	(8)	
B			2	60.0	.42		
C			2	62.5	.51		
D			2	47.0	.45		
11A	925° Q <sub>o</sub> { 425°/60 C <sub>a</sub> ..... 525°/60 C <sub>a</sub> ..... 600°/60 C <sub>a</sub> .....	Cr, 0.95; Mo, 0.73; C, 0.25	2	60.5	.46	(8)	
B			2	57.0	.46		
C			2	50.5	.48		
30. Fe-Cr-V-C, Cr-V-Steels							
1A	900° Q <sub>o</sub> { 425°/60 C <sub>a</sub> ..... 525°/60 C <sub>a</sub> ..... 625°/60 C <sub>a</sub> ..... 900° C <sub>a</sub> .....	Cr, 0.93; V, 0.16; C, 0.41	2	62.0	0.42	(8)	
B			2	52.0	.40		
C			2	52.0	.48		
D			2	46.0	.52		
2A	900° Q <sub>o</sub> { 425°/60 C <sub>a</sub> ..... 525°/60 C <sub>a</sub> ..... 625°/60 C <sub>a</sub> .....	Cr, 0.93; V, 0.20; C, 0.40	2	69.0	.51	(8)	
B			2	55.5	.48		
C			2	43.5	.43		
31. Fe-Mo-C, Mo-Steels							
1	875° Q <sub>o</sub> , 450°/60 C <sub>a</sub> .....	Mo, 0.34; C, 0.44	2	69.0	0.50	(8)	
2A	870° Q <sub>w</sub> { 360°/60 C <sub>a</sub> ..... 420°/60 C <sub>a</sub> .....	Mo, 0.37; C, 0.38	2	67.5	.46	(8)	
B			2	59.5	.45		
C	840° C <sub>a</sub> .....	Mo, 0.67; C, 0.41	2	35.0	.48	(8)	
3A	870° Q <sub>w</sub> { 420°/60 C <sub>a</sub> ..... 500°/60 C <sub>a</sub> .....		2	64.0	.46		
B			2	64.5	.52		
C	840° C <sub>a</sub> .....		2	38.0	.45		

TABLE 4.—ENDURANCE LIMITS UNDER REVERSED PLANE BENDING STRESSES (UPTON-LEWIS MACHINE). \*—(Continued)

Key No.†	Treatment	Approximate composition	$10^{-6}n$ †	$FL_0$ * UTS	Lit.	
31. Fe-Mo-C, Mo-Steels.—(Continued)						
4A B	$875^\circ Q_o \left\{ \begin{array}{l} 475^\circ/60 C_a \dots\dots \\ 550^\circ/60 C_a \dots\dots \end{array} \right.$	Mo, 0.73; C, 0.4	2 2	67.5 60.0	0.50 .47	(8)
5A B C D	$900^\circ Q_o \left\{ \begin{array}{l} 425^\circ/60 C_a \dots\dots \\ 500^\circ/60 C_a \dots\dots \\ 600^\circ/60 C_a \dots\dots \end{array} \right.$	Mo, 1.05; C, 0.46	2 2 2 2	69.0 67.5 67.5 52.0	.45 .48 .49 .53	(8)
6A B C	$900^\circ Q_o \left\{ \begin{array}{l} 425^\circ/60 C_a \dots\dots \\ 500^\circ/60 C_a \dots\dots \\ 575^\circ/60 C_a \dots\dots \end{array} \right.$	Mo, 3.0; C, 0.36	2 2 2	73.0 76.0 81.0	.48 .55 .65	(8)
32. Fe-Ni-C, Ni-Steels						
3A B C	$860^\circ Q_o \left\{ \begin{array}{l} 415^\circ/60 C_a \dots\dots \\ 510^\circ/60 C_a \dots\dots \\ 595^\circ/60 C_a \dots\dots \end{array} \right.$	Ni, 3.0; C, 0.41	2 2 2	77.5 63.5 60.0	0.43 .47 .50	(8)
8A B D	$830^\circ/30 C_f, \left\{ \begin{array}{l} 590^\circ/120 C_f \dots\dots \\ 830^\circ/15 Q_o \left\{ \begin{array}{l} 650^\circ/120 C_f \dots\dots \end{array} \right. \end{array} \right.$	Ni, 3.4; C, 0.41	2 2 2	37.0 32.5 31.5	.43 .39 .44	(20)
33. Fe-Ni-Ce-C, Ni-Ce-Steels						
1A B C	$860^\circ Q_o \left\{ \begin{array}{l} 595^\circ/60 C_a \dots\dots \\ 455^\circ/60 C_a \dots\dots \\ 425^\circ/60 C_a \dots\dots \end{array} \right.$	Ni, 2.86; Ce, 0.33-0.58; C, 0.43	2 2 2	53.5 58.5 67.5	0.45 .42 .40	(8)
34. Fe-Ni-Cr-C, Ni-Cr-Steels						
2 7 8A B	$825^\circ Q_o, 525^\circ/60 C_a \dots\dots$ $865^\circ Q_o, 475^\circ/60 C_f \dots\dots$ $810^\circ Q_o \left\{ \begin{array}{l} 525^\circ/60 C_a \dots\dots \\ 625^\circ/60 C_a \dots\dots \end{array} \right.$	Ni, 1.23; Cr, 0.65; C, 0.47 Ni, 2.49; Cr, 0.83; C, 0.37 Ni, 2.56; Cr, 0.83; C, 0.36	2 2 2 2	58.5 60.0 48.0 46.0	0.52 .50 .45 .52	(8) (8) (8)
14A B C	$A, 830^\circ Q_o, 330^\circ Q_o \dots\dots$ $A, 830^\circ/30 Q_o, \left\{ \begin{array}{l} C_f \dots\dots \end{array} \right.$ $790^\circ Q_o, 650^\circ/60 C_w \dots\dots$	Ni, 3.33; Cr, 0.87; C, 0.24	2 2 2	36.5 32.5 35.0	.37 .41 .44	(20)
36. Fe-Ni-Cr-Ce-C, Ni-Cr-Ce-Steels						
1A B	$810^\circ Q_o \left\{ \begin{array}{l} 525^\circ/60 C_a \dots\dots \\ 420^\circ/60 C_a \dots\dots \end{array} \right.$	For compositions v. Table 1	2 2	53.0 68.0	0.46 .45	(8)
2 3 4	$825^\circ Q_o, 525^\circ/60 C_a \dots\dots$ $805^\circ Q_o, 500^\circ/60 C_f \dots\dots$ $810^\circ Q_o, 525^\circ/60 C_a \dots\dots$		2 2 2	58.0 56.5 54.0	.55 .50 .50	(8) (8) (8)
37. Fe-Ni-Cr-Mo-C, Ni-Cr-Mo-Steels						
1A B	$825^\circ Q_o \left\{ \begin{array}{l} 625^\circ/60 C_a \dots\dots \\ 425^\circ/60 C_a \dots\dots \end{array} \right.$	For compositions v. Table 1	2 2	52.0 70.5	0.41 .45	(8)
2 3A B C	$825^\circ Q_o, 525^\circ/60 C_a \dots\dots$ $790^\circ Q_o \left\{ \begin{array}{l} 630^\circ/60 C_a \dots\dots \\ 525^\circ/60 C_a \dots\dots \\ 430^\circ/60 C_a \dots\dots \end{array} \right.$		2 2 2 2	62.0 49.5 61.0 72.0	.52 .43 .42 .43	(8) (8)
4 5	$865^\circ Q_o, 625^\circ/60 C_f \dots\dots$ $810^\circ Q_o, 625^\circ/60 C_a \dots\dots$		2 2	48.5 56.0	.43 .51	(8) (8)
6A B C D E F	$810^\circ Q_o \left\{ \begin{array}{l} 650^\circ/60 C_a \dots\dots \\ 625^\circ/60 C_a \dots\dots \\ 525^\circ/60 C_a \dots\dots \\ 425^\circ/60 C_a \dots\dots \\ 325^\circ/60 C_a \dots\dots \\ 150^\circ/60 C_a \dots\dots \end{array} \right.$		2 2 2 2 2 2	50.5 58.5 70.5 67.5 70.5 95.0	.46 .49 .49 .44 .41 .43	(8)
7 8	$790^\circ Q_o, 610^\circ/60 C_a \dots\dots$ $790^\circ Q_o, 635^\circ/60 C_a \dots\dots$		2 2	47.0 50.5	.40 .44	(8) (8)
38. Fe-Ni-Cr-V-C, Ni-Cr-V-Steels						
1 2A B C	$825^\circ Q_o, 525^\circ/60 C_a \dots\dots$ $810^\circ Q_o, 625^\circ/60 C_a \dots\dots$ $805^\circ Q_o, 560^\circ/60 C_f \dots\dots$ $810^\circ Q_o, 425^\circ/60 C_a \dots\dots$	For compositions v. Table 1	2 2 2 2	62.0 53.0 50.0 70.5	0.55 .49 .44 .48	(8) (8)
39. Fe-Ni-Mo-C, Ni-Mo-Steels						
2A B	$860^\circ Q_o \left\{ \begin{array}{l} 620^\circ/60 C_a \dots\dots \\ 595^\circ/60 C_a \dots\dots \end{array} \right.$	Ni, 2.95; Mo, 0.70; C, 0.37	2 2	65.0 65.0	0.52 .50	(8)
40. Fe-Ni-V-C, Ni-V-Steels						
1A B C	$870^\circ Q_o \left\{ \begin{array}{l} 610^\circ/60 C_a \dots\dots \\ 510^\circ/60 C_a \dots\dots \\ 400^\circ/60 C_a \dots\dots \end{array} \right.$	Ni, 2.94; V, 0.12; C, 0.36	2 2 2	67.5 74.0 70.5	.52 .51 .38	(8)
41. Fe-Ni-Zr-C, Ni-Zr-Steels						
1	$860^\circ Q_o, 370^\circ/60 C_a \dots\dots$	Ni, 3.00; Zr, 0.24; C, 0.43	2	77.0	0.39	(8)
43. Fe-V-C, V-Steels						
3A B C	$900^\circ C_a \dots\dots$ $840^\circ Q_o \left\{ \begin{array}{l} 555^\circ/60 C_a \dots\dots \\ 475^\circ/60 C_a \dots\dots \end{array} \right.$	V, 0.20; C, 0.50	2 2 2	46.0 53.0 56.5	0.52 .51 .47	(8)

TABLE 5.—ENDURANCE LIMITS UNDER REVERSED TORSIONAL STRESSES\*

Key No.†	Treatment	Approximate composition	Millions of reversals, 10 <sup>-6</sup> n‡	Endurance limit, kg./mm <sup>2</sup> . F L <sub>0</sub> [Def. 17(b)]*	Endurance limit Tensile strength	Lit.			
1. Al									
2	A, single crystal†.....		15	1.17	0.22	(9.5)			
11. Cu, Electrolytic or Commercially Pure									
1	As received {	R <sub>0</sub> .....	Cu, 99.993	30	4.2	0.15	(16)		
2		R <sub>h</sub> .....	Cu, 99.992	10	2.8	.13	(16)		
13. Cu-Al, Al-Bronzes									
4A	As received {	R <sub>h</sub> .....	Al, 5.6	30	7.9	0.16	(16)		
6A			Al, 9.1	20	7.0	.11	(16)		
7A			Al, 10.0	40	9.1	.16	(16)		
12A			Al, 10.4	60	12.0	.17	(16)		
17. Cu-Ni									
4A	As received {	R <sub>h</sub> .....	Ni, 44.7 (constantan)	30	10.2	0.21	(16)		
B				R <sub>h</sub> , 790°/60 C <sub>f</sub>	20	12.0	.24		
18. Cu-Ni-Cr									
1A	As received, F.....		Ni, 34.2; Cr, 4.1	60	13.7	0.20	(16)		
20. Cu-Ni-Zn									
1A	As received {	R <sub>h</sub> .....	Ni, 20; Zn, 5	30	9.1	0.22	(16)		
B				R <sub>h</sub> , 760°/60 C <sub>f</sub>	30	9.1	.25		
21. Cu-Sn, Bronzes									
3	As received, R <sub>0</sub> .....		Sn, 4.66	70	8.4	0.21	(16)		
22. Cu-Zn, Brasses									
4	As received, R <sub>0</sub> .....		Zn, 28.2	20	6.3	0.19	(16)		
13A	Q <sub>i</sub> , T <sub>p</sub> {		Zn, 40.1 (Muntz metal)	250°.....	6	3.9	.07	(16)	
B				344°.....	20	5.3	.09		
C				425°.....	30	6.0	.12		
23. Fe, Commercially Pure									
1A	A 1000°/30 C <sub>f</sub> , Armco iron..		C, 0.012	10	11.0	0.38	(9)		
2A	As received, A <sub>b</sub> , ingot iron..		C, 0.02	10	8.8	.30	(20)		
24. Fe-C, C-Steels									
3	N 850°.....	%C {	0.13	10	16.5	0.34	(9)		
19A	As received.....		.24	10	9.8	.23	(16)		
20	As received, R.....		.25	10	11.0	.24	(9)		
21	F.....		.25	10	11.6	.22	(16)		
31	850°/15 C <sub>a</sub> .....		.33	10	15.9	.27	(11)		
37B	810°/15 C <sub>f0</sub> .....		.37	10	11.2	.22	(20)		
39A	845°/30 C <sub>f</sub> .....		.38	10	12.7	.26	(20)		
B	845°/30 C <sub>a</sub> .....			10	12.3	.23			
C	930°/120 Q <sub>0</sub> , 845°/30 C <sub>f</sub> ....			10	11.2	.22			
D	845°/30 Q <sub>0</sub> {		670°/30 C <sub>f</sub> ....	10	15.1	.26			
E			540°/30 C <sub>f</sub> ....	10	11.6	.19			
F			430°/30 C <sub>f</sub> ....	10	14.4	.22			
42	As taken from service§.....		.41	10	10.2	.18	(16)		
48	850°/60 Q <sub>w</sub> , 480°/120 C <sub>f</sub> ....		.46	10	20.0	.22	(16)		
50B	925°/20 C <sub>a</sub> .....		.49	10	14.1	.22	(20)		
C	Same, 775° Q <sub>w</sub> , 650° C <sub>f</sub> ....			10	18.3	.27			
52A	845°/15 C <sub>a</sub> .....		.52	10	15.5	.22	(20)		
B	Same, 790°/15 Q <sub>w</sub> , 650° C <sub>a</sub> ..			10	22.2	.28			
60	N 800°.....		.65	10	15.2	.19	(9)		
65A	790°/30 C <sub>f</sub> .....		.81	10	13.4	.21	(16)		
66B	870°/15 C <sub>a</sub> {		.93		790°/15 C <sub>f</sub> .....	10	11.5	.19	(20)
C					790°/15 Q <sub>0</sub> {	10	20.4	.25	
D					455°/30 C <sub>a</sub>	10	36.5	.28	
69A	795°/15 {		1.20		860°/15 C <sub>f0</sub> .....	10	17.2	.21	(20)
B	C <sub>f</sub> {				800° Q <sub>0</sub> , 460°/15 C <sub>a</sub>	10	33.7	.27	
27. Fe-Cr-C, Cr-Steels (Stainless Steels)									
5A	900°/60 Q <sub>w</sub> {		Cr, 12; C, 0.42	540°/60 C <sub>a</sub> ....	10	30.2	0.39	(16)	
B				650°/60 C <sub>a</sub> ....	10	26.0	.31		
7	As received, R <sub>h</sub>   .....		Cr, 13; C, 0.1	40	18.3	.23	(20)		
11A	900°/60 Q <sub>w</sub> {		Cr, 15; C, 0.85	480°/60 C <sub>a</sub> ....	10	45.7	.28	(16)	
B				565°/60 C <sub>a</sub> ....	10	41.5	.35		
C				650°/60 C <sub>a</sub> ....	10	26.0	.28		
D				As received, A.....	10	15.1	.19		

TABLE 5.—ENDURANCE LIMITS UNDER REVERSED TORSIONAL STRESSES.\*—(Continued)

Key No.†	Treatment	Approximate composition	$10^{-6}n$ ‡	$FL_0$ *	$\frac{FL_0}{UTS}$	Lit.
12A	$\left\{ \begin{array}{l} 480^\circ/60\ C_a \dots \\ 900^\circ/60\ Q_w \left\{ \begin{array}{l} 565^\circ/60\ C_a \dots \\ 650^\circ/60\ C_a \dots \end{array} \right. \end{array} \right.$	Cr, 15; C, 0.4	10	28.2	0.24	(16)
B			10	21.1	.24	
C			10	21.1	.26	
D			10	16.9	.22	
13A	$900^\circ/60\ Q_w, 480^\circ/60\ C_a \dots$	Cr, 16; C, 0.6	10	33.0	.24	(16)
B	As received, A.....	10	15.5	.21		
30. Fe-Cr-V-C, Cr-V-Steels						
5	Sv.....	Cr, 1.0; V, 0.16; C, 0.45	10	15.1	0.21	(16)
32. Fe-Ni-C, Ni-Steels						
4	As taken from service¶.....	Ni, 3.05; C, 0.4	10	16.5	0.25	(16)
7A	$900^\circ/120\ Q_o, 800^\circ/30\ C_f \dots$	Ni, 3.35; C, 0.3	10	14.4	.24	(16)
B	$840^\circ/60\ Q_w, 485^\circ/60\ C_f \dots$		10	37.2	.36	
C	$800^\circ/60\ C_f \dots$		10	19.7	.27	
F	$\left\{ \begin{array}{l} 620^\circ/30\ C_f \dots \\ 880^\circ/30\ Q_o \left\{ \begin{array}{l} 570^\circ/30\ C_f \dots \\ 510^\circ/30\ C_f \dots \end{array} \right. \end{array} \right.$		10	26.4	.33	
H			10	33.7	.30	
J			10	31.6	.29	
K	$800^\circ/60\ Q_o, 480^\circ/30\ C_f \dots$		10	24.6	.30	
8A	$830^\circ/30\ C_f \left\{ \begin{array}{l} 590^\circ/120\ C_f \\ 830^\circ/15\ Q_o \left\{ \begin{array}{l} 650^\circ/120\ C_f \end{array} \right. \end{array} \right.$	Ni, 3.4; C, 0.4	10	26.0	.30	(20)
B			10	25.3	.31	
C	$830^\circ/30\ C_f, 810^\circ/15\ Q_w, C\ to\ 500^\circ, S_h\ 590^\circ/60\ C_f \dots$		10	23.2	.28	
D	$785^\circ/60\ C_f \dots$		10	20.4	.29	
10A	$790^\circ/60\ C_f \dots$	Ni, 3.6; C, 0.42	10	15.8	.20	(16)
C	$790^\circ/60\ Q_o, 480^\circ/60\ C_f \dots$		10	26.7	.32	
D	$790^\circ/60\ Q_w \left\{ \begin{array}{l} 590^\circ/60\ C_f \dots \\ 480^\circ/60\ C_f \dots \end{array} \right.$		10	32.7	.35	
F			10	33.0	.31	
12	$840^\circ/60\ Q_w, 480^\circ/120\ C_f \dots$	Ni, 3.7; C, 0.3	10	25.3	.24	(16)
34. Fe-Ni-Cr-C, Ni-Cr-Steels						
3	$840^\circ/60\ Q_w, 480^\circ/120\ C_f \dots$	Ni, 1.36; Cr, 0.65; C, 0.37	10	32.3	0.29	(16)
14A	$A\ 830^\circ\ Q_o, 330^\circ\ Q_o \dots$	Ni, 3.3; Cr, 0.87; C, 0.24	10	26.7	.27	(20)
B	$A\ 830^\circ/30\ Q_o, \left\{ \begin{array}{l} 650^\circ/60\ C_f \\ 790^\circ\ Q_o \left\{ \begin{array}{l} 650^\circ/60\ Q_w \end{array} \right. \end{array} \right.$		10	22.1	.28	
C			10	23.9	.30	
D	$A, 830^\circ/30\ C_a, 790^\circ/30\ C_f \dots$		10	17.6	.29	
21A	$R_h\ (2\ passes), R_c\ (cyclops\ metal) \dots$	Ni, 19.7; Cr, 8.3; C, 0.33	10	26.1	.23	(20)
35. Fe-Ni-Cr-Cu-C, Ni-Cr-Cu-Steels (Stainless Steels)						
3	As received, A.....	Ni, 23; Cr, 5.4; C, 0.24	10	14.8	0.22	(16)
6	As received, A.....	Ni, 28; Cr, 8.4; C, 0.45	10	15.5	.20	(16)
43. Fe-V-C, V-Steels						
2	$795^\circ/60\ Q_w, 480^\circ/120\ C_f \dots$	V, 0.16; C, 0.5	10	30.2	0.30	(16)
48. Ni, Commercially Pure						
2A	As received, $R_h \dots$	Ni, 99.07	70	14.1	0.33	(16)
4B	$R_c, 288^\circ/60\ C_f \dots$	Ni, 98.95	20	13.0	.11	(16)
F	$R_c, 870^\circ/60\ C_f \dots$		20	12.0	.24	
50. Ni-Cu						
4	As received.....	Cu, 27.3	10	14.0	0.22	(20)
7A	$R_h \dots$	Cu, 29.5	20	13.4	.21	(16)

\* Stresses calculated by usual formulae of theory of elasticity.

† See footnotes to Table 2.

‡ The mechanical properties depend to some extent on the relative positions of the specimen and crystallographic axis.

§ Submarine crank-shaft.

|| Stainless iron.

¶ Battleship propeller shaft.



TABLE 6.—ENDURANCE LIMITS UNDER CYCLES OF DIRECT STRESS WITH VARIOUS MEAN STRESSES

Key No. *	Treatment	Approximate composition	$10^{-6} \times$ number of reversals *	$M$ , mean unit stress, kg/mm <sup>2</sup>	$R/2$ , endurance half range [Def. 17(e)]	$UTS$ , ultimate tensile strength	$R/UTS$	Lit.
22. Cu-Zn, Brasses								
14A	As received, R..... Naval brass, $\alpha\beta$	Cu, 58.5; Zn, 40.1	2 H	9.5	22.9	45.3	1.01	(12)
			2 H	5.1	21.6	45.3	0.955	
			2 H	0.0	18.9	45.3	.825	
			2 H	+ 6.3	16.5	45.3	.73	
			2 H	9.8	15.1	45.3	.665	
			2 H	12.2	13.8	45.3	.61	
24. Fe-C, C-Steels								
4	Rh.....	C, 0.13	8 H	-19.2	15.3	39.7	0.77	(12)
			8 H	-14.7	16.9	39.7	.85	
			8 H	-8.2	18.5	39.7	.93	
			8 H	0.0	20.5	39.7	1.03	
			8 H	+ 7.8	19.3	39.7	0.97	
			8 H	15.5	16.9	39.7	.85	
18A	As received.....	C, 0.24	1	0.0	22.7	59.2	.765	(25)
			1	15.1	15.1	59.2	.51	
B	A.....	C, 0.24	1	0.0	20.7	57.6	.72	(25)
			1	14.6	14.6	57.6	.505	
23	As received, R.....	C, 0.27	1	0.0	21.2	51.5	.825	(25)
			1	16.2	16.2	51.5	.63	
25	As received, R.....	C, 0.29	1	0.0	21.7	54.7	.79	(25)
			1	16.7	16.7	54.7	.61	
32	As received.....	C, 0.34	1	0.0	22.8	58.5	.78	(25)
			1	17.1	17.1	58.5	.585	
33	As received, R.....	C, 0.38	1	0.0	23.3	62.0	.75	(25)
			1	17.6	17.6	62.0	.57	
51	As received.....	C, 0.51	1	0.0	20.3	70.4	.585	(25)
			1	15.2	15.2	70.4	.43	
54	As received.....	C, 0.57	1	0.0	26.8	73.6	.73	(25)
			1	20.2	20.2	73.6	.55	
57	As received.....	C, 0.62	1	0.0	22.4	72.6	.62	(25)
			1	17.6	17.6	72.6	.485	
58	As received.....	C, 0.63	1	0.0	28.0	81.0	.69	(25)
			1	21.4	21.4	81.0	.53	
62	As received.....	C, 0.72	1	0.0	21.2	89.0	.475	(25)
			1	18.3	18.3	89.0	.41	
64	As received.....	C, 0.79	1	0.0	23.6	63.1	.75	(25)
			1	16.7	16.7	63.1	.53	
32. Fe-Ni-C, Ni-Steels								
5	As received, R.....	Ni, 3.1; C, 0.12	1	0.0	22.8	46.0	0.955	(25)
			1	18.3	18.3	46.0	.795	
6	As received, R.....	Ni, 3.25; C, 0.38	1	0.0	30.9	50.4	1.23	(25)
			1	14.2	27.6	50.4	1.10	
			1	22.1	22.1	50.4	0.875	
			1	27.3	17.9	50.4	.71	
8A	830°/30 Cf, 830°/15 Q <sub>o</sub> , 590°/120 Cf.....	Ni, 3.4; C, 0.41	10	0.0	30.9	87.0	.71	(20)
			10	3.4	30.4	87.0	.70	
8B	830°/30 Cf, 830°/15 Q <sub>o</sub> , 650°/120 Cf.....		10	0.0	26.0	78.6	.66	(20)
			10	3.4	31.0	78.6	.79	
			10	11.0	25.6	78.6	.65	
8D	785°/60 Cf.....		10	0.0	25.7	71.5	.72	(20)
			10	9.3	21.6	71.5	.605	
9A	As received, R.....	Ni, 3.56; C, 0.14	1	0.0	27.0	50.0	1.08	(25)
			1	17.3	17.3	50.0	0.69	
13	As received, R.....	Ni, 4.7; C, 0.50	1	0.0	29.7	63.4	.94	(25)
			1	21.6	21.6	63.4	.825	

TABLE 6.—ENDURANCE LIMITS UNDER CYCLES OF DIRECT STRESS WITH VARIOUS MEAN STRESSES.—(Continued)

Key No.*	Treatment	Approximate composition	$10^{-6} \times$ number of reversals*	$M$ , mean unit stress, kg/mm <sup>2</sup>	$R/2$ , endurance half range [Def. 17(e)]	$UTS$ , ultimate tensile strength	$R/UTS$	Lit.
<b>34. Fe-Ni-Cr-C, Ni-Cr-Steels</b>								
18	Treatment not stated	Ni, 3.6; Cr, 0.6; C, 0.30	8 H	-15.8	42.2	80.9	1.04	(15)
			8 H	0.0	36.2	80.9	0.895	
			8 H	+23.8	27.6	80.9	.685	
			8 H	28.3	26.8	80.9	.665	
			8 H	31.5	20.0	80.9	.495	
			8 H	39.4	14.6	80.9	.36	
			8 H	47.3	15.7	80.9	.39	
			8 H	53.9	11.3	80.9	.28	
			8 H	66.3	6.1	80.9	.15	
			8 H	66.3	6.1	80.9	.15	

\* See footnotes to Table 2.

TABLE 7.—ENDURANCE LIMITS UNDER CYCLES OF TORSIONAL STRESS WITH VARIOUS MEAN STRESSES

Key No.*	Treatment	Approximate composition	Millions of reversals, $10^{-6} \times$	$M$ , mean unit stress, kg/mm <sup>2</sup>	$R/2$ , endurance half range, kg/mm <sup>2</sup> [Def. 17(e)]	$UTS$ , ultimate tensile strength, kg/mm <sup>2</sup>	$R/UTS$	Lit.
24. Fe-C, C-Steels								
48	805°/60 Q <sub>w</sub> , 480°/120 C <sub>f</sub> ...	C, 0.46	10	0.0	20.0	92.7	0.43	(15)
			10	14.1	21.1	92.7	.455	
			10	20.4	20.4	92.7	.44	
50B	925°/20 C <sub>a</sub> .....	C, 0.49	10	0.0	14.0	64.3	.435	(20)
			10	3.4	13.5	64.3	.42	
			10	13.0	13.0	64.3	.405	
50C	925°/20 C <sub>a</sub> , 775° Q <sub>w</sub> , 650° C <sub>f</sub> (sorbite).		10	0.0	18.3	68.1	.54	(20)
			10	17.6	17.6	68.1	.52	
69A	795°/15 C <sub>f</sub> , 860°/15 C <sub>f0</sub> ...	C, 1.20	10	0.0	17.2	82.2	.42	(20)
			10	17.2	17.2	82.2	.42	
69B	795°/15 C <sub>f</sub> , 800° Q <sub>o</sub> , 460°/15 C <sub>a</sub>		10	0.0	33.7	126.5	.53	(20)
			20	31.3	31.3	126.5	.50	
32. Fe-Ni-C, Ni-Steels								
7B	840°/60 Q <sub>w</sub> , 485°/60 C <sub>f</sub> ...	Ni, 3.35; C, 0.31	10	0.0	37.3	102.5	0.73	(16)
			10	17.9	33.4	102.5	.65	
			10	33.4	33.4	102.5	.65	
			10	44.6	23.6	102.5	.46	
8A	830°/30 C <sub>f</sub> , 830°/15 Q <sub>o</sub> , 590°/120 C <sub>f</sub>	Ni, 3.4; C, 0.4	10	0.0	26.0	86.9	.60	(20)
			10	24.6	24.7	86.9	.57	
8B	830°/30 C <sub>f</sub> , 830°/15 Q <sub>o</sub> , 650°/120 C <sub>f</sub>		10	0.0	25.3	78.8	.645	
			10	5.5	21.9	78.8	.555	
8D	785°/60 C <sub>f</sub> .....		10	0.0	20.4	71.4	.57	
			10	4.9	19.7	71.4	.55	
			10	20.0	20.0	71.4	.56	
12	840°/60 Q <sub>w</sub> , 480°/120 C <sub>f</sub> ...	Ni, 3.74; C, 0.28	10	0.0	25.3	103.5	.49	(16)
			10	23.9	23.9	103.5	.46	
34. Fe-Ni-Cr-C, Ni-Cr-Steels								
3	840°/60 Q <sub>w</sub> , 480°/120 C <sub>f</sub> ...	Ni, 1.4; Cr, 0.65; C, 0.37	10	0.0	32.3	112.6	0.575	(16)
			10	30.6	30.6	112.6	.545	
14D	As received, A, 830°/30 C <sub>a</sub> , 790°/30 C <sub>f</sub>	Ni, 3.3; Cr, 0.87; C, 0.24	10	0.0	17.6	61.4	.58	(20)
			10	3.9	15.8	61.4	.52	
			10	16.2	16.2	61.4	.53	
43. Fe-V-C, V-Steel								
2	795°/60 Q <sub>w</sub> , 480°/120 C <sub>f</sub> ...	V, 0.16; C, 0.50	10	0.0	30.2	100.9	0.60	(16)
			10	28.5	28.5	100.9	.565	
			10	37.2	27.4	100.9	.545	

\* See footnotes to Table 2.

TABLE 8.—ENDURANCE LIMITS AT VARIOUS TEMPERATURES, REVERSED DIRECT STRESSES

Key No.*	Treatment	Approximate composition	Temp., °C	Millions of reversals, $10^{-6}n^*$	Endurance limit, kg/mm <sup>2</sup> , $FL_0$ [Def. 17 (b)]†	$(FL_0)_{10}/(FL_0)_{20}$	Lit.
<b>8. Al-Si</b>							
6A	G <sub>m</sub> M.....	Si, 12.7	15 180	10 H 10 H	6.0 4.4	1.00 0.735	(22)
<b>24. Fe-C, Carbon Steels</b>							
60	N 800°.....	C, 0.65	20 305	10 H 10 H	30.7 23.5	1.00 0.765	(9)
<b>25. Fe-C, Cast Irons</b>							
1	As cast.....	Graphite, 1.70; combined C, 0.56, "granfin"	20 350 500	6 H 6 H 6 H	15.0 13.4 14.2	1.00 0.895 0.945	(12)
<b>32. Fe-Ni-C, Ni-Steels</b>							
1	As received.....	Ni, 2.9; C, 0.4	26 370	10 H 10 H	1.7 25.9	1.00 0.82	(27)
<b>49. Ni-Cr</b>							
1	As received, R <sub>h</sub> .....	Ni, 80; Cr, 19	18 200 300 400 600 700	10 H 10 H 10 H 10 H 10 H 10 H	23.6 24.8 27.9 27.9 24.8 24.0	1.00 1.05 1.18 1.18 1.05 1.01	(22)
<b>51. Ni-Cu-Mn</b>							
1	As received, R.....	Ni, 69; Cu, 28; Mn, 2.4	15 100 200 300 500 600	10 H 10 H 10 H 10 H 10 H 10 H	25.1 21.0 20.0 20.0 18.4 14.1	1.00 0.84 .80 .80 .73 .56	(22)

\* See footnotes to Table 2.

TABLE 9.—ENDURANCE LIMITS AT VARIOUS TEMPERATURES, REVERSED BENDING STRESSES (ROTATING BEAM MACHINES)

Key No.*	Treatment	Approximate composition	Temp., °C	Millions of reversals, $10^{-6}n^*$	Endurance limit kg/mm <sup>2</sup> $FL_0$ [Def. 17(b)]†	$(FL_0)_{10}/(FL_0)_{20}$	Lit
3. Al-Cu-Mg							
5	R <sub>h</sub> , 480° Q <sub>w</sub> V .....	Cu, 4.0; Mg, 0.5	20	2	16.6	1.00	(13)
			150	2	11.3	0.68	
8	R <sub>h</sub> , 480° Q <sub>w</sub> V .....	Cu, 5.0; Mg, 0.75	20	2	16.6	1.00	(13)
			150	3	12.5	0.75	
9	R <sub>h</sub> , 480° Q <sub>w</sub> V .....	Cu, 6.0; Mg, 0.75	20	3	16.1	1.00	(13)
			150	3	7.9	0.49	
4. Al-Cu-Ni-Mg							
1	R <sub>h</sub> ("magnalite") .....	Cu, 2.0; Ni, 1.5; Mg, 1.0	20	4	14.2	1.00	(13)
			150	4	11.0	0.78	
4	480° Q <sub>h</sub> V .....	"Y" alloys, Cu, 4; Ni, 2.0; Mg, 1.5	20	3	14.2	1.00	(13)
			150	3	10.3	0.73	
5	480° Q <sub>h</sub> V .....		20	3	16.3	1.00	(13)
			150	3	12.9	0.79	
6	520° Q <sub>h</sub> V .....		20	10	16.1	1.00	(13)
			150	3	13.2	0.82	
6. Al-Mg							
1	R <sub>h</sub> ("aeromin") .....	Mg, 6.2	20	3	10.3	1.00	(13)
			150	3	8.6	0.84	

TABLE 9.—ENDURANCE LIMITS AT VARIOUS TEMPERATURES, REVERSED BENDING STRESSES (ROTATING BEAM MACHINES).—(Continued)

Key No.*	Treatment	Approximate composition	Temp., °C	Millions of reversals, $10^{-6}n^*$	Endurance limit, kg/mm <sup>2</sup> , $FL_0$ [Def. 17 (b)]†	$(FL_0)_{10}/(FL_0)_{20}$	Lit.
<b>10. Al-Zn-Cu</b>							
5	R <sub>h</sub> , 350° Q V, "E" alloy....	Zn, 20; Cu, 2.5	20 150	2 2	15.3 8.0	1.00 0.52	(13)
6	R <sub>h</sub> "A" alloy.....	Zn, 20.3; Cu, 2.9	20 150	2 2	13.7 7.1	1.00 0.52	(13)
<b>24. Fe-C, C-Steels</b>							
50 B	925°/20 C <sub>a</sub> .....	C, 0.49	21 290 380 425 470 540 620	18 20 10 10 12 15	25.3 27.4 29.5 31.0 29.6 23.9 16.9	1.00 1.08 1.17 1.22 1.77 0.94 .67	(20)
68	790°/30 C <sub>f</sub> , 790°/30 Q <sub>o</sub> ("spring steel")	C, 1.02	21 165 305 480 565	10 10 10 10 12	73.8 68.4 60.5 52.8 38.0	1.00 0.93 .82 .72 .52	(20)
<b>34. Fe-Ni-Cr-C, Ni-Cr-Steels</b>							
15A	830°/30 C <sub>f</sub> , 790°/15 Q <sub>o</sub> , 425°/30 C <sub>a</sub>	Ni, 3.3; Cr, 0.18; C, 0.41	20 240 345 470 540	10 10 10 10 10	53.5 57.7 52.9 47.9 40.9	1.00 1.08 0.99 .90 .76	(20)
15B	830°/30 C <sub>f</sub> , 790°/15 Q <sub>o</sub> , 650°/30 C <sub>a</sub>		20 240 345 470 540	10 10 10 10 10	52.1 52.7 47.1 43.6 38.7	1.00 1.01 0.90 .84 .74	(20)
21B	R <sub>h</sub> (2 passes), R <sub>c</sub> , 940°/30 C <sub>f</sub> ("cyclops metal")	Ni, 19.7; Cr, 8.3; C, 0.33	20 260 470 565	80 13 20 10	39.4 36.6 32.4 26.1	1.00 0.93 .82 .66	(20)

\* See footnotes to Table 2.

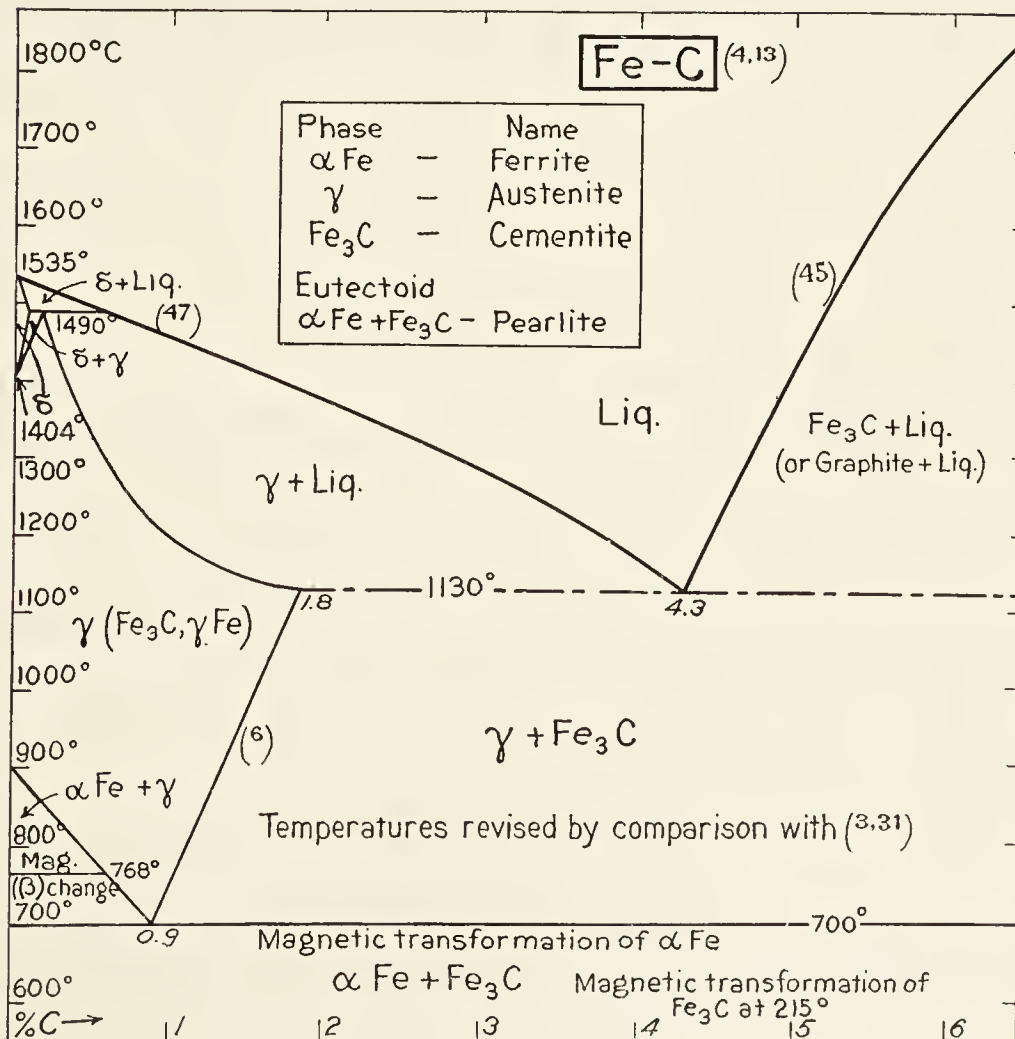
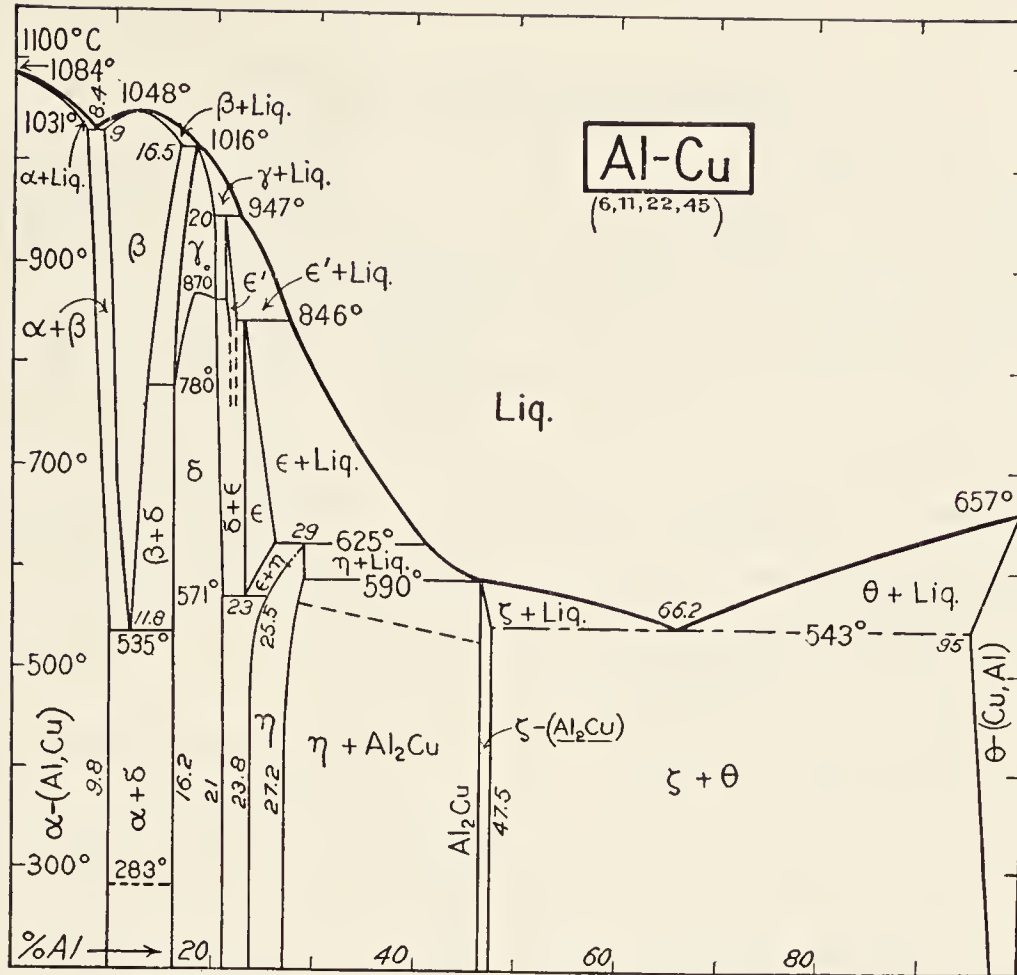
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## SPECIAL PROPERTY-TABLE

The following tables are arranged to facilitate the selection of a metal or alloy having an extreme (high or low) value of a given mechanical property at room temperature. The bold-face numbers represent a scale of values of the property in question. The numbers in the interval between any two scale values are page numbers by means of which the reader may locate an alloy having a value (of the property in question) which lies within this interval.

ULTIMATE TENSILE STRENGTH, *UTS*, kg/mm<sup>2</sup> (DEF. 4)

*Ferrous*: **241**: 479, 513. **230**: 513, 530, 531. **220**: 478, 479, 509, 510, 513, 531, 532. **200**: 478, 479, 502, 503, 505, 509, 510, 512, 532. **180**: 479, 507, 511, 512, 513, 530, 531. **175**: . . . **20**: 488, 497, 498, 508, 526, 527. **10**: 488, 490, 497, 498, 508, 523, 527. **3**.

*Non-ferrous*: **420**: 592. **160**: 585, 592. **112**: 560, 573, 575, 576, 578, 579, 581, 582. **80**: 481, 560, 575-579, 581, 582, 583, 585, 592. **70**: 534, 538, 555, 556, 575-585, 592. **60**: 538, 546, 554, 555, 556, 560, 563, 574-585, 592. **50**: . . . **5**: 533, 535, 545, 546, 547, 549, 551, 553, 556, 557, 567, 570, 584, 592, 593. **1**: 586, 593. **0**.

YIELD POINT IN TENSION, *YP*, kg/mm<sup>2</sup> (DEF. 3)

*Ferrous*: **203**: 479, 513, 531. **190**: 478, 479, 510, 513. **180**: 478, 479, 511, 530, 531. **170**: 478, 479, 503, 507, 511, 531. **160**: 478, 479, 481, 510, 513. **151**: . . . **20**: 478, 480, 482, 488, 489, 490, 491, 493, 508, 514, 523. **10**: 482, 523. **3.6**.

*Non-ferrous*: **88**: 581, 582. **70**: 575, 579, 581-583. **60**: 481, 534, 538, 555, 556, 560, 575, 577-582. **40**: . . . **3.9**: 533, 534, 536, 537, 543, 552. **1.8**.

REDUCTION IN AREA, *RA*, % (DEF. 8)

*Ferrous*: **100**: 488, 490, 498. **80**: 478, 481, 488, 498, 523. **75**: . . . **2.2**: 491, 492, 493, 510, 513, 521, 529, 530, 531, 532. **1.0**: 479, 510, 513, 521, 524, 531. **0.0**: 490, 491, 492, 493, 497, 508, 510, 513, 520, 524, 529, 530, 532.

*Non-ferrous*: **100**: 592, 593. **95**: 533, 548, 549, 553, 574. **80**: 533, 536, 548, 549, 552, 553, 555, 560, 574, 581, 583. **77**: . . . **2.0**: 533, 545, 556, 557, 560, 562, 575, 579. **0.4**: 575, 579, 586, 593. **0.0**.

PER CENT ELONGATION, *El* (DEF. 7)

*Ferrous*: **76**: 488, 498, 512. **60**: 478, 482, 488, 490, 498, 512. **50**: . . . **1.0**: 491, 492, 493, 501, 503, 510, 513, 520, 521, 523, 524, 525, 530, 531, 532. **0.5**: 478, 490, 491, 492, 493, 508, 513, 521, 522, 523, 524, 525, 529, 530, 532. **0.0**.

*Non-ferrous*: **160**: 547, 576. **95**: 533, 535, 548, 551, 555, 557, 573-576, 581-583. **70**: . . . **1.0**: 480, 533, 534, 536, 537, 544, 545, 546, 551, 559-561, 565, 567, 568, 570, 575-577, 579, 581, 586. **0.0**.

BRINELL HARDNESS NUMBER, *BHN* (DEF. 12)

*Ferrous*: **817**: 495, 510, 514, 531. **600**: 495, 506, 510, 513, 514, 521, 523, 530, 531. **570**: 495, 503, 510, 513, 514, 523, 530, 531. **550**: 513, 514, 531. **520**: 506, 510, 513, 514, 532. **509**: . . . **99**: 478, 494, 525, 526. **90**: 478, 514, 525, 529. **80**: 478, 494, 529. **51**.

*Non-ferrous*: **540**: 576, 588. **390**: 561, 576, 588. **300**: 480, 567, 576, 577, 579, 581, 582, 586-588, 592, 593. **220**: 480, 556, 576, 577, 581-583, 586, 588. **190**: 480, 546, 556, 576, 577, 581-584, 586. **175**: 480, 539, 546, 556, 577, 580-582, 584, 585, 588. **160**: 480, 539, 554, 556, 577, 579-587. **154**: . . . **10**: 556, 557, 561, 576. **3.0**.



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69. Proceedings and Transactions of the Royal Society of Canada.
70. Recueil des travaux chimiques des Pays-Bas.
71. Rendiconti dell'accademia dell scienze fisiche e matematiche. (Classe della società reale di Napoli.)
72. Rendiconti reale istituto Lombardo di scienze e lettere.
74. Revue de métallurgie.
- 74E. Revue de métallurgie, Extraits.
75. Sitzungsberichte Akademie der Wissenschaften in Wien, mathematisch-naturwissenschaftliche Klasse.
76. Sitzungsberichte der preussischen Akademie der Wissenschaften.
77. Stahl und Eisen.
78. Transactions of the American Electrochemical Society.
80. Transactions of the American Institute of Mining and Metallurgical Engineers.
81. Transactions of the American Ceramic Society. (*Continued in 1917 by No. 38.*)
82. Transactions of the Ceramic Society (England).
83. Transactions of the Faraday Society.
85. Transactions of the Optical Society (London).
86. University of Illinois, Engineering Experiment Station, Bulletins.
88. Verhandlungen der physikalischen Gesellschaft zu Berlin. *See also No. 96.*
89. Wissenschaftliche Abhandlungen der physikalisch-technischen Reichsanstalt.
91. Zeitschrift für analytische Chemie.
92. Zeitschrift für angewandte Chemie.
93. Zeitschrift für anorganische und allgemeine Chemie. (*Name changed in 1915 from Zeitschrift für anorganische Chemie.*)
94. Zeitschrift für Krystallographie. (*Name changed in 1921 from Zeitschrift für Krystallographie und Mineralogie.*)
95. Zeitschrift für Metallkunde. (*Formerly Internationale Zeitschrift für Metallographie.*)
96. Zeitschrift für Physik. (Verhandlungen der physikalischen Gesellschaft zu Berlin, 1882-1898; Verhandlungen der deutschen physikalischen Gesellschaft, 1899-1902; Berichte der deutschen physikalischen Gesellschaft, 1903-1919; Zeitschrift für Physik, 1920- .)
97. Zeitschrift für technische Physik.
98. Zeitschrift des Vereines deutscher Ingenieure.
100. Sprechsaal, Zeitschrift für die keramischen, Glas- und verwandten Industrien.
101. Elektrotechnische Zeitschrift.
102. Ceramique.
103. Keramische Rundschau.
104. Berichte der deutschen keramischen Gesellschaft.
105. Journal of the Society of Glass Technology.
106. Revue générale de l'électricité.
107. Electrical World.
109. National Advisory Committee for Aeronautics, Annual Reports.
112. Dinglers polytechnisches Journal.
114. Electric Journal.
115. Engineering.
117. Scientific Proceedings of the Royal Dublin Society.
119. Proceedings of the American Institution of Electrical Engineers. (*Discontinued in 1919.*)
120. General Electric Review.
121. Electrician.
122. Journal of the American Society of Mechanical Engineers. *See No. 56.*



124. Silikat-Zeitschrift.
125. Archiv für Elektrotechnik. (*Supplement to No. 101.*)
128. Journal of the Washington Academy of Sciences.
129. Transactions of the American Institute of Electrical Engineers.
133. British Association for the Advancement of Science, Reports.
134. Bulletin de l'académie des sciences de l'union des républiques soviétiques socialistes. (*Formerly Bulletin de l'académie imperial des sciences de St. Petersburg; name changed in 1917 to Bulletin de l'académie des sciences de Russie; present name dates from 1925.*)
135. Chemical News and Journal of Industrial Science. (*Name changed in 1921 from Chemical News and Journal of Physical Science.*)
136. Chemiker Zeitung.
137. Kongelige Danske Videnskabernes Selskab, Mathematisk-fysiske Meddelelser.
138. Societas scientiarum fennica. Commentationes physico-mathematicae.
139. Ferrum.
140. Journal of the Iron and Steel Institute, London.
141. Journal of Biological Chemistry.
142. Journal of the Society of Chemical Industry, Japan. (*Formerly Journal of Chemical Industry, Japan.*)
143. Journal of the Franklin Institute.
148. Zeitschrift für die gesamte Kälte-Industrie.
149. Archives des sciences physiques et naturelles. (Bibliothèque britannique, 1796-1815; Bibliothèque universelle des sciences, belles-lettres et arts, 1816-1835; Bibliothèque universelle de Genève, 1836-1845; Supplément à la bibliothèque universelle de Genève. Archives des sciences physiques et naturelles, 1846-1847; Bibliothèque universelle de Genève. Archives des sciences physiques et naturelles, 1848-1857; Bibliothèque universelle, revue suisse et étrangère. Archives des sciences physiques et naturelles, 1858-1861; Bibliothèque universelle et revue suisse. Archives des sciences physiques et naturelles, 1862-1877; Bibliothèque universelle. Archives des sciences physiques et naturelles, 1878- .)
152. Carnegie Institution of Washington Publications.
153. Minutes of Proceedings of the Institution of Civil Engineers.
154. Iowa Geological Survey, Bulletin.
155. Missouri Bureau of Geology and Mines.
156. U. S. Geological Survey, Bulletin.
157. U. S. Department of Agriculture, Bulletin.
158. New York State Museum, Bulletin.
159. Science Reports of the Tôhoku Imperial University. Series I, Mathematics, Physics and Chemistry.
160. Arkansas Geological Survey, Annual Reports.
161. Mitteilungen aus dem königlichen technischen Versuchsanstalten zu Berlin. *See also No. 312.*
162. Mitteilungen aus dem mech.-tech. Laboratorium der technischen Hochschule in München.
163. Minnesota, Geological and Natural History Survey.
164. Colorado, Biennial Report Capitol Managers.
166. Science.
168. Communications from the Physical Laboratory at the University of Leiden.
169. Annales de l'Institut Polytechnique Pierre-le-Grand, Petrograd.
172. International Congress of Applied Chemistry.
173. Analyst, London.
174. Transactions of the Royal Society of Edinburgh.
176. Chemisch Weekblad, Amsterdam.
182. Proceedings of the Chemical Society, London. (*Continued as No. 4.*)
184. American Journal of Pharmacy.
185. Chemisches Centralblatt.
186. Bulletin de la classe des sciences, académie royale de Belgique.
187. Metall und Erz, Zeitschrift für Metalhüttenwesen und Erzbergbau, einschl. Aufbereitung.
188. Nachrichten von der königlichen Gesellschaft der Wissenschaften zu Göttingen. Geschäftliche Mitteilungen; mathematisch-physikalische Klasse.
189. Centralblatt für Mineralogie, Geologie und Paläontologie.
- 190B. Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, Beilage Band.
192. Metallurgie. (*Divided into Nos. 139 and 187.*)
197. Proceedings of the National Academy of Sciences.
198. Revue générale des sciences pures et appliquées.
199. Le Radium. (*Merged into No. 51 in 1920.*)
200. Jahrbuch der Radioaktivität und Elektronik. (*Combined with Physikalische Zeitschrift in 1924.*)
201. Proceedings of the Cambridge Philosophical Society.
204. Photographic Journal.
205. Biochemische Zeitschrift.
208. Physica, Nederlandsch Tijdschrift voor Natuurkunde.
209. Japanese Journal of Chemistry.
210. Scientific Papers, Institute of Physical-Chemical Research, Tokyo.
212. Transactions of the American Society for Steel Treating.
216. Giornale di chimica industriale ed applicata. (Annali di chimica applicata, 1914; *continued as* Giornale di chimica applicata; *combined with* Giornale di chimica industriale, March, 1920, to form Giornale di chimica industriale ed applicata.)
218. Naturwissenschaften.
219. Proceedings of the Physico-Mathematical Society of Japan.
220. Jern-Kontorets Annaler, Stockholm.
223. Journal of General Physiology.
226. Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung zu Düsseldorf.
227. Proceedings of the Society for Experimental Biology and Medicine.
230. Biochemical Journal.
231. U. S. Public Health Service, Public Health Reports.
238. Travaux et mémoires du bureau international des poids et mesures.
242. Vierteljahrsschrift der naturforschenden Gesellschaft, Zürich.
243. Zeitschrift für Instrumentenkunde.
244. Journal of the Society of Automotive Engineers.
248. Proceedings of the University of Durham Philosophical Society.
251. Proceedings of the Royal Society of Victoria, Melbourne.
252. Chemische Umschau auf dem Gebiete der Fette, Oele, Wachse und Harze. (*Before 1916 Chemische Revue über die Fett- und Harz Industrie.*)
253. Lubrication.
255. Bulletin of the American Institute of Mining and Metallurgical Engineers. (*Continued as No. 329.*)
257. Bulletin of the Imperial Institute, London. (*Before 1903, Imperial Institute Journal.*)
258. Le cuir. Edition technique. (*Name changed Nov., 1923 to Le cuir technique.*)
259. Collegium.
260. Indian Forest Records.
261. Journal of the American Leather Chemists' Association.
262. Journal of the International Society of Leather Trades' Chemists. (*Before Oct., 1925, Journal of the Society of Leather Trades' Chemists.*)
263. Leather Trades' Review.



264. Ledertechnische Rundschau. (*Technical supplement of Der Lederindustrie.*)
265. Queensland Agricultural Journal.
267. Philippine Journal of Science.
273. Berichte der pharmazeutischen Gesellschaft. *See* No. 293.
275. International Sugar Journal.
276. Chemical Age, London.
279. Zeitschrift für Untersuchung der Nahrungs- und Genussmittel sowie der Gebrauchsgegenstände. Zeitschrift für Untersuchung der Lebensmittel.
285. Journal of Mathematics and Physics.
287. Kolloidchemische Beihefte.
290. Journal of the Society of Dyers and Colourists.
291. Arbeiten aus dem Reichsgesundheitsamte.
293. Archiv der Pharmazie. (*Combined with No. 273 in 1924 to form Archiv der Pharmazie und Berichte der deutschen pharmazeutischen Gesellschaft.*)
295. Proceedings of the American Wood-Preservers' Association.
296. Kunststoffe, Zeitschrift für Erzeugung und Verwendung veredelter oder chemisch hergestellter Stoffe.
299. British Aeronautical Research Committee. Reports and Memoranda.
306. Journal of the American Society of Naval Engineers.
307. Iron and Coal Trades Review.
308. Fortschritte der Mineralogie, Kristallographie und Petrographie.
309. Bulletin of the Lewis Institute, Structural Materials Research Laboratory, Chicago.
310. Transactions of the National Lime Manufacturers' Association.
311. France-Belgique. (*Revue de l'ingénieur et index technique merged with this in 1922.*)
312. Mitteilungen aus dem Materialprüfungsamt und dem Kaiser-Wilhelm-Institut für Metallforschung zu Berlin-Dahlem. (*Mitteilungen aus dem königlichen technischen Versuchsanstalten zu Berlin, 1883-1903; in 1904 became Mitteilungen aus dem königlichen Materialprüfungsamt zu Gross-Lichterfelde West; later becoming Mitteilungen aus dem königlichen Materialprüfungsamt zu Berlin-Lichterfelde West; name changed in 1919 to Mitteilungen aus dem Materialprüfungsamt zu Berlin-Lichterfelde West; name changed in 1920 to Mitteilungen aus dem Materialprüfungsamt zu Berlin-Dahlem; present name dates from 1923.*)
313. U. S. Bureau of Mines, Reports of Investigations.
314. Tonindustrie-Zeitung.
315. Memorial des poudres. (*Formerly Memorial des poudres et salpêtres.*)
317. Chemische Industrie. (*Combined with No. 92 in 1921; separated again in 1923.*)
324. Canadian Chemistry and Metallurgy.
325. Proceedings of the Royal Institution of Great Britain.
329. Mining and Metallurgy. (*Transactions of the American Brass Founders' Association, 1908-11; Transactions of the American Institute of Metals, 1912-16; Journal of the American Institute of Metals, 1917-18; discontinued in 1918 and incorporated with Bulletin of the American Institute of Mining Engineers; with No. 148, 1919, this Bulletin became Bulletin of the American Institute of Mining and Metallurgical Engineers; with No. 154, 1919, name changed again to Mining and Metallurgy.*)
338. Researches of the Electro-technical Laboratory, Tokyo.
340. Philippine Agriculturist.
341. Journal of Agricultural Research.
342. Annales de chimie analytique et de chimie appliquée et revue de chimie analytique réunies.
343. Zeitschrift für öffentliche Chemie. (*Suspended at end of 1922.*)
344. Apotheker Zeitung.
345. Bulletin des sciences pharmacologiques.
346. Malayan Agricultural Journal. (*Formerly Bulletin of the Department of Agriculture, Federated Malay States.*)
347. Pharmaceutical Journal and Pharmacist.
348. Cotton Oil Press.
349. Seifensieder-Zeitung und Rundschau über die Harz-, Fett- und Ölindustrie mit dem Bleiblat: Der chem.-techn. Fabrikant.
350. Les matières grasses.
351. Journal of State Medicine, London.
352. Milchwirtschaftliche Zentralblatt. (*Name changed in 1912 from Milch-Zeitung.*)
353. Academia Caesarea Leopoldino Carolina Germanica naturae curiosorum.
354. National Physical Laboratory, Collected Researches and Reports, London.
355. The Engineer, London.
356. Journal of the Royal Society of Arts.
357. Anales de la asociación química Argentina. (*Name changed Jan., 1921 from Anales de la sociedad química Argentina.*)
358. Journal of the Institution of Petroleum Technologists and Record of Transactions.
359. Petroleum Age. (*Petroleum; name changed to Petroleum Magazine, and then back to Petroleum; in Sept., 1921 combined with Petroleum Age to form Petroleum Age including Petroleum; name changed back to Petroleum Age, Dec., 1925.*)
360. National Petroleum News.
361. Petroleum, Zeitschrift für die gesamten Interessen der Mineralöl-Industrie und des Mineralöl-Handels. (*Formerly Petroleum, Zeitschrift für die gesamten Interessen der Petroleum-Industrie und des Petroleum-Handels.*)
362. Chemické Listy pro vedu a průmysl.
363. Petroleum Review. (*Replaced by No. 364.*)
364. Petroleum Times. *See* No. 363.
365. Bureau of Standards, Circulars.
366. Feuerungstechnik.
367. Oesterreichische Chemiker-Zeitung.
368. Proceedings of the Institution of Automobile Engineers, London.
369. Gornyi zhurnal.
370. Memoirs of the American Academy of Arts and Sciences, Boston.
371. University Geological Survey of Kansas, Reports.
372. Vercin zur Beförderung des Gewerbetreibenden, Verhandlungen.
373. Chemisch-technisches Repertorium. (*Supplement to No. 136.*)
374. Oil and Colourman's Journal.
375. Polytechnisches Centralblatt.
376. Automotive Industries.
377. Bulletin de la section scientifique de l'académie Roumaine.
378. Chimie et industrie.
379. Journal of the Japanese Ceramic Society.
380. Gesundheits-Ingenieur.
381. Automobile Engineer and Internal Combustion Engineering. (*Automobile Engineer, London, 1910 to Oct., 1912; Internal Combustion Engineering, Oct., 1912 to Jan., 1914; present name since Jan., 1914.*)
382. Refrigerating Engineering. (*Transactions of the American Society of Refrigerating Engineers, 1905-13; American Society of Refrigerating Engineers Journal; present name dates from July, 1922.*)



383. Revue générale du froid et des industries frigorifiques.
384. Le génie civil, Paris.
385. Journal of the American Society of Heating and Ventilating Engineers.
386. Canada Department of Mines.
387. Mineral Industry.
388. Översigt av Förfhandlingar kongl. Svenska Vetenskaps-Akademien.
389. South African Journal of Industries. (*United with the Official Labour Gazette of the Union of South Africa in 1925 to form the South African Journal of Industries and Labour Gazette.*)
390. Indian Forest Bulletin.
391. Indian Forester.
392. Indian Forest Pamphlet.
393. American Society for Testing Materials Standards.
394. Fuel in Science and Practice.
395. Engineering and Mining Journal-Press. (*Formed in April, 1922 by the combining of Engineering and Mining Journal with Mining and Scientific Press; name changed July, 1926 to Engineering and Mining Journal.*)
396. Gas Journal. (*Formerly Journal of Gas Lighting and Water Supply.*)
397. Gas- und Wasserfach. (*Name changed Jan., 1922 from Journal für Gasbeleuchtung und verwandte Beleuchtungsarten sowie für Wasserversorgung.*)
398. Memoirs and Proceedings of the Manchester Literary and Philosophical Society.
399. Colliery Guardian and Journal of the Coal and Iron Trades.
400. Beama.
401. Revue de l'industrie minérale. (Bulletin de la société de l'industrie minérale; *name changed Jan., 1921 to Revue de la société de l'industrie minérale; name changed to Revue de l'industrie minérale.*)
402. Technique moderne.
403. Proceedings of the Institution of Mechanical Engineers.
404. Engineering News-Record. (*Formed by the combining of Engineering News with Engineering Record.*)
405. Glückauf, Berg- und Hüttenmännische Zeitschrift.
407. Jornal de Sciencias Matematicas, Physicas e Naturaes, Lisbon.
408. Journal de mathématiques pures et appliquées (Paris). (*Continues Annales de mathématiques pures et appliquées; present name dates from 1836.*)
409. Bayerisches Industrie- und Gewerbe-Blatt. (Kunst- und Gewerbe-Blatt, 1815-68; *present name dates from 1869.*)
410. Edinburgh Philosophical Journal, 1819-26; Edinburgh New Philosophical Journal, 1826-64; Quarterly Journal of Science, 1864-70; Quarterly Journal of Science and Annals of Mining, Metallurgy, Engineering, Industrial Arts, Manufactures and Technology, 1871-79; Monthly Journal of Science and Annals of Astronomy, Biology, Geology, Industrial Arts, Manufactures and Technology, 1879-85.
411. Proceedings of the North East Coast Institute of Engineers and Shipbuilders.
412. Horseless Age. (*Merged into Motor Age in 1918.*)
413. Journal of the Royal Aeronautical Society. (Annual Report of the Royal Aeronautical Society, 1866-96; *superseded by Aeronautical Journal; later Journal of the Royal Aeronautical Society.*)
414. Mitteilungen über Forschungsarbeiten auf den Gebiete des Ingenieurwesens hrsg. vom Vereine deutscher Ingenieure.
415. Journal of the Textile Industry.
416. Brennstoff-Chemie.
417. Iron and Steel Institute Carnegie Scholarship Memoirs.
418. Pottery Gazette and Glass Trade Review.
419. Ohio Journal of Science. (*Name changed Nov., 1915 from Ohio Naturalist.*)
420. Bulletin de la société d'encouragement pour l'industrie nationale.
421. Journal of West Scotland Iron and Steel Institute.
422. American Machinist.
423. Transactions of the American Foundrymen's Association. (*Journal of the American Foundrymen's Association, 1896-1904.*)
424. Oesterreichische Zeitschrift für Berg- und Hüttenwesen. (*Merged into Montanistische Rundschau.*)
425. Deutsche Mechaniker-Zeitung. (Beiblatt zur Zeitschrift für Instrumentenkunde.)
427. Physikalische Berichte. (Beiblätter zu den Annalen der Physik und Chemie; Beiblätter *united with Fortschritte der Physik and Halbmonatliches Literaturverzeichnis to form Physikalische Berichte.*)
428. Repertorium für Experimental-Physik für physikalische Technik für mathematische und astronomische Instrumentenkunde. (*Before 1867 was Repertorium für physikalische Technik für mathematische und astronomische Instrumentenkunde; also known as Carl's Repertorium.*)
429. Memoirs of the College of Science, Kyoto Imperial University. (*Before 1914 was part of Memoirs of the College of Science and Engineering, Kyoto Imperial University.*)
430. Iron Age.
431. Revue de la société russe de métallurgie.
433. Annual Report of the Royal Mint, London.
434. Scientific Transactions of the Royal Dublin Society.
435. Proceedings of the Institution of British Foundrymen.
436. Reports of the Research Department, Royal Arsenal, Woolwich.
437. Japanese Journal of Physics.
438. Transactions of the American Society of Mechanical Engineers.
439. Mémoires et compte rendu des travaux de la société ingénieurs civils de France.
440. Metal Industry and the Iron Foundry (London).
441. India Rubber Journal.
442. Annals of Botany.
443. Archief voor Rubbercultuur in Nederlandsch-Indië.
445. Zeitschrift des Vereins der deutschen Zucker-Industrie. (*Before 1898 was Zeitschrift des Vereins für die Rubenzucker-industrie.*)
446. Zeitschrift für die Zuckerindustrie der Cechoslovakischen Republik. (*Formerly Zeitschrift für die Zuckerindustrie in Böhmen.*)
447. India Rubber World.
449. Caoutchouc et gutta percha.
450. Transactions of the Institution of the Rubber Industry.
456. Gummi-Zeitung.
459. Electrical Review and Industrial Engineer. (*Formerly Electrical Review and Western Electrician.*)
460. Deutsche Zuckerindustrie, Wochenblatt für Landwirtschaft, Fabrikation und Handel.
468. Kongliga Svenska Vetenskaps-Akademien, Handlingar.
469. Bulletin of the Institute of Physical and Chemical Research (Tokyo).
470. Memoirs of the College of Engineering, Kyushu Imperial University.
471. Army Ordnance.
472. Papier-Fabrikant (Tech.-Wiss. Teil).
473. Cellulosechemie.

- B3. Landolt-Börnstein, Physikalisch-chemische Tabellen. 5th ed. Berlin, Springer, 1923.
- B4. Singer, Die Keramik im Dienste von Industrie und Volkswirtschaft. Braunschweig, Vieweg, 1923.
- B5. Rieke and Gary, Die Prüfung von Porzellan, 1922. Reprinted from 104, 3: 5; 22.
- B6. Gilchrist and Klinefelter, High Voltage Porcelain Insulators. Westinghouse Electric and Manufacturing Company, Special Pub. 1690, 1925.
- B7. Peck, Dielectric Phenomena in High Voltage Engineering. New York, McGraw-Hill Book Company, Inc., 1915.
- B8. Rziha and Seidener, Starkstromtechnik. Taschenbuch für Elektrotechniker. 5th ed. Berlin, Ernst, 1922.
- B10. Doelter, Handbuch der Mineralchemie. Leipzig, Steinkopff, 1912-
- B12. Friese, Das Porzellan als Isolier- und Konstruktions-Material in der Elektrotechnik. Klosterlausnitz, 1904.
- B26. Hirschwald, Handbuch der bautechnischen Gesteinprüfung. Berlin, Borntraeger, 1912.
- B27. Hermann, Gesteine für Architektur und Sculptur. Berlin, Borntraeger, 1914.
- B28. Johnson, Comparison of Experiments on American and Foreign Building Stones. New Haven, Hamlen. Reprinted from *American Journal of Science and Arts*, 11: 1; 51.
- B29. Merrill, Stones for Building and Decoration. 3rd ed. New York, Wiley, 1903.
- B30. Popplewell and Carrington, Properties of Engineering Materials. London, Methuen, 1923.
- B31. Schweizerische Geotechnische Kommission, Die natürlichen Bausteine und Dachschiefer der Schweiz. Berne, 1915.
- B32. U. S. Ordnance Department, Tests of Metals and Other Materials. Washington, Government Printing Office, 1894.
- B33. U. S. Geological Survey, The Stone Industry in 1903. Washington, Government Printing Office, 1903.
- B61. Ullmann, Encyclopädie der techn. Chemie. Wien, Urban and Schwarzenberg, 1914-23.
- B68. Abraham, Asphalt and Allied Substances, Their Occurrence, Mode of Production, Uses in the Arts and Methods of Testing. New York, Van Nostrand, 1920.
- B71. Mellor, Treatise on Inorganic and Theoretical Chemistry. London, Longmans, 1922-
- B72. Bunsen, Gasometrische Methoden. 2nd ed. Braunschweig, 1877.
- B73. Berthelot, Thermochemie. Paris, Gauthier-Villars, 1897.
- B74. Rieke, Das Porzellan. Hannover, 1910.
- B75. Société d'encouragement pour l'industrie nationale, Contribution à l'étude des argiles et de la céramique. Paris, Chapuy, 1906.
- B76. Winkelmann, Handbuch der Physik. Leipzig, Barth, 1905-8.
- B77. Marks, Mechanical Engineers' Handbook. 2nd ed. New York, McGraw-Hill Book Company, Inc., 1914.
- B79. de Vries, Estate Rubber. Batavia, Drukkerijen Ruyter & Co., 1920.























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